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September 10, 2021

VIA ELECTRONIC SUBMISSION

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US Environmental Protection Agency
Land, Chemicals & Redevelopment Division 3LD20
1650 Arch Street
Philadelphia, PA 19103

**Re: Interim Measures Work Plan
Marcus Hook Industrial Complex – Area of Interest 7
100 Green Street
Marcus Hook, Pennsylvania
Delaware County**

Dear Mr. Bilash:

Please find the attached Interim Measures (IM) Workplan prepared by Sanborn, Head and Associates, Inc. (on behalf of Evergreen Resources Management) for Area of Interest (AOI) 7 located within the Marcus Hook Industrial Complex (MHIC or Site) in Marcus Hook, Pennsylvania. The IM Work Plan has been prepared in response to the Environmental Protection Agency's (EPA's) June 23, 2021 correspondence which requested this plan within 45 days of receipt of the June 23, 2021 letter, but later an extension to September 10, 2021 submittal date was granted by EPA. This IM Workplan discusses results of additional investigation activities at the Site undertaken in July and August 2021, presents a site conceptual model based upon arsenic conditions in soil and groundwater at Site, provides remedial alternatives, and proposes further investigation activities to aid future Site decision making.

If you have any questions regarding this IM Workplan, please do not hesitate to contact me.

Regards,

Evergreen Resources Management Operations

Tiffani L. Doerr, P.G.

Cc: Dana Aunkst, Director, EPA Land, Chemicals & Redevelopment Division
Scott Cullinan, PE, Evergreen Resources Management Operations
Colleen Costello, PG, Sanborn Head & Associates, Inc.

INTERIM MEASURES WORKPLAN

AOI 7, MARCUS HOOK INDUSTRIAL COMPLEX

*Prepared for Evergreen Resource Management Operations
File No. 4862.00
September 10, 2021*

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1.0 INTRODUCTION

This Interim Measures (IM) Workplan has been prepared on behalf of Evergreen Resource Management Operations (Evergreen) for Area of Interest (AOI) 7 (AOI 7) located within the Marcus Hook Industrial Complex (MHIC or Site). The MHIC is located in southeastern Pennsylvania and northern Delaware on the Delaware River (Figure 1). On October 5, 2012, Energy Transfer Partners, L.P. (ETP) and Sunoco, Inc. (R&M) announced the merger of the facility into Sunoco Partners Marketing & Terminals, L.P. (SPMT) as a wholly owned subsidiary of ETP. The Marcus Hook property was transferred to SPMT on April 1, 2013. SPMT transitioned the former Marcus Hook Refinery into an operation referred to as the SPMT Marcus Hook Industrial Complex. Evergreen assumed any liabilities of Sunoco occurring prior to April 13, 2013. As part of the sale of the property SPMT agreed to be responsible for liabilities which are caused by or arise out of the ownership or operation of the property after April 1, 2013. SPMT is currently operating under a RCRA Part B permit with Corrective Action obligations to the USEPA.

This IM Workplan has been prepared in response to the Environmental Protection Agency's (EPA's) June 23, 2021 correspondence which requested that Evergreen submit an IM Workplan for implementing IM at AOI 7 within 45 days of receipt of the June 23, 2021 letter. Also, within the EPA's June 23, 2021 correspondence was a request to complete additional investigation activities. A conference call was held with the EPA, Evergreen and Sanborn Head on July 7, 2021 to discuss the activities to be completed for inclusion in the IM Workplan. Evergreen had already completed some of the activities requested in the EPA's June 23, 2021 letter based on earlier correspondence from the EPA and was planning to complete additional activities starting July 13, 2021. Based on the proposed scope of work to be included in the IM Workplan, Evergreen requested an extension for the IM Workplan to be submitted to the EPA on September 10, 2021, which was approved by the EPA.

1.1 Objectives

Three questions were identified by Evergreen to be addressed to be able to respond to the EPA's request for an IM for arsenic in groundwater in AOI 7. These questions included: 1) what is the source material for the observed arsenic concentrations, 2) what conditions exist that are resulting in the mobilization of the arsenic; and 3) what is the appropriate remedial action objective for the IM? The results and data analysis from the 2021 investigation activities included in this IM Workplan been structured to provide a path forward to address these questions.

1.2 Site Description

The MHIC is located on the north bank of the Delaware River (River) in the Borough of Marcus Hook, Delaware County, Pennsylvania, with portions of the facility in Lower Chichester Township, Pennsylvania and Claymont, New Castle County, Delaware (see Figure 1). The MHIC frontage extends approximately 4,800 feet along the northern banks of the Delaware River. The MHIC, which is located on industrial property, covers approximately 585 acres of land with access restricted by fencing and security measures. Current operation of the facility (24 hours per day) includes the processing and storage of

light hydrocarbon products plus support facilities. The area surrounding the facility is characterized by a mixture of residential, commercial, recreational, active industrial, and vacant industrial properties. The MHIC has been divided into 8 AOIs, as shown on Figure 2. AOI 7, which is located within MHIC, is located in Delaware and consists of approximately 50 acres of land bounded on the southeast by the Delaware River, the southwest by a property boundary with Honeywell's Delaware Valley Works (DVW) and by the Pennsylvania-Delaware state line/AOI 5 on the northeast. Middle Creek runs east-west then turns and runs north-south through AOI 7, as shown in Figure 3.

Honeywell's DVW property, is a former chemical manufacturing plant located in Claymont, Delaware and Marcus Hook, PA. The DVW consists of approximately 100 acres, which is divided by Route 13 into two separate plants, referred to as the "North Plant" and "South Plant". The South Plant includes Solid Waste Management Unit 9 (SWMU 9) which was used for disposal of pesticides and related wastes, arsenic, materials from DDT and DDD production, and laboratory samples disposal. SWMU 9 is located adjacent to the MHIC AOI 7 site. A drainage channel referred to as "the sluiceway" traverses the southern portion of the South Plant and discharges to the Delaware River approximately 2,500 feet downstream of Middle Creek. The location of the South Plant and SWMU 9 is shown on Figure 4.

1.3 Summary of MHIC Dredging Activities

Maintenance dredging is performed periodically at the MHIC within berthing areas adjacent to the Piers. Dredging depths within the berth areas were approximately 40 feet at the outer docks (USACE 2001). As shown on the navigational chart for the Marcus Hook reach of the Delaware River (Appendix A), the nearshore area adjacent to the MHIC is mapped as shallow water, with deeper water present on the south side of the MHIC piers. A bathymetric survey conducted for the MHIC dredging project in 2002 (see Appendix A) shows the bottom surface is steeply sloped beginning at a point approximately 530 feet from shoreline (depth of approximately 15 feet) to a point 640 feet from shoreline (depth of approximately 40 feet) corresponding to the edge of the wharf in the vicinity of water intake RW-7 and Dock 3C (see Figure MH-3, Transect A-A in Appendix A). Similar conditions in the MHIC dock area are noted in the 2015 bathymetric survey provided in Appendix A.

1.4 Historical Site Use

AOI 7 is part of the MHIC facility that has a long history of petroleum transportation, storage, and refining of fuels and petrochemicals. Operations began in 1902, and the facility was owned and operated by Sunoco since its inception as Sun Oil in 1901. AOI 7 was generally undeveloped until the late 1950s. Prior to development, AOI 7 generally consisted of a low-lying floodplain and marsh area, as shown by the 1898 historical topographical map included in Appendix B. The surface of AOI 7 was significantly modified by filling and Middle Creek was relocated several times during development between 1930s to late 1950s. Figure 5 presents a summary of these changes over time to the shoreline and orientation of Middle Creek in AOI 7. Appendix B presents the 1898 historical topographical map and historical aerial photographs of AOI 7 and SWMU 9 in 1937, 1953, 1958 and 1965, which are described below. This discussion is included in this IM Workplan

since it is helpful to understand depositional patterns related to potential source areas and former surface water features that may influence current day groundwater flow through preferential pathways.

1898 Topographical Map

The outline of the MHIC AOIs, with AOI 7 outlined in black is shown overlain on the 1898 historical topographic map, which was first presented in the AOI RFI (GHD, 2017). This map shows that approximately half of AOI 7 is open water or march land and that Middle Creek (Walkers Run) is located on the eastern edge of AOI 7. This figure also shows that the marsh area existed in the majority of SWMU 9 at this time.

1937 Aerial Photo

- *AOI 7* -The marsh area shown on the 1899 topographical map is not shown on the 1937 aerial, but Middle Creek has been shown to be slightly re-routed and be present on the eastern side of AOI 7. The southwest portion of AOI 7 where the elevated arsenic detections in groundwater have been observed was not made land in the 1937 aerial photo, but rather was still part of the Delaware River. Apparent outwash/sedimentation from SWMU 9 on the adjacent DVW into surface water at AOI 7 are shown in the 1937 aerial photo, as evidenced by the white material migrating from SWMU 9 along the shoreline and towards AOI 7.
- *SWMU 9* – Approximately half of the current extent of SWMU 9 was still surface water in 1937. Waste deposition on the land surface is apparent in SWMU 9, based on the white areas in the 1937 aerial photo. As mentioned above, materials also appear to be migrating from SWMU 9 to AOI 7 and deposited in the sediments along the shoreline of AOI 7.

1953 Aerial Photo

- *AOI 7* – The shoreline has been straightened in the 1953 aerial photo since the 1937 photo. Middle Creek is more channelized and now crosses the center of AOI 7. There is an additional area of made land along the southwestern boundary of AOI 7, in the general area where the deposition from SWMU 9 was observed in 1937 and current elevated arsenic detections are observed. The newly made land also appears to have overland depositions from SWMU 9.
- *SWMU 9* –A bulkhead further out in the Delaware River is apparent in the 1953 aerial, which is assumed to be used to form an expansion of the impoundment for the alum mud settling. As mentioned above, overland materials also seem to be migrating from SWMU 9 to AOI 7.

1958 Aerial Photo

- *AOI 7* – In the 1958 aerial photo, there is additional made land in the southwestern portion of AOI 7 and Middle Creek has been completely channelized and re-routed through the center of AOI 7 and along the western AOI 7 boundary to its current configuration.

- **SWMU 9** – The 1958 aerial photo shows that the impoundment had more deposition than shown in the 1953 aerial photo. The remainder of SWMU 9 also appears to have more materials placed than shown in the 1953 aerial photo, but drainage channels into the impoundment were also clearly present.

1965 Aerial Photo

- **AOI 7** – The 1965 aerial photo shows the build out of the ethylene and ethylene oxide units and the remainder of the riverfront margin of AOI 7 filled to the current bulkhead line. Materials were placed to bring the elevation of the area to 15 feet above mean sea level (AMSL) and then eventually to the current elevation of approximately 19 feet AMSL in the southern portion of AOI 7.
- **SWMU 9** – Continued deposition is apparent in the alum mud impoundment in the 1965 aerial photo. There is a large white area in SWMU 9 that may be gypsum waste being stockpiled.

2.0 ENVIRONMENTAL HISTORY

The following summarizes Evergreen's understanding of the basis for EPA's June 23, 2021 request for this IM Workplan for AOI 7 based on the completed environmental investigations in AOI 7 and the adjacent DVW facility.

2.1 AOI 7

The following provides an overview for activities in AOI 7 in relation to the EPA's June 23, 2021, requested IM Workplan, which focuses on arsenic in groundwater and porewater. A significant amount of additional investigation has been completed for AOI 7 that is not summarized below. This additional information can be found in the RCRA Facility Investigation (RFI) Report (2017, revised 2019) and other environmental reports included in the References (Section 11.0).

RCRA Corrective Action

Sunoco, Inc. (R&M) entered the facility into Corrective Action with the EPA in order to satisfy Corrective Action obligations under Resource Conservation and Recovery Act (RCRA). Evergreen assumed any liabilities of Sunoco arising from the environmental condition at the property existing or occurring prior to December 30, 2013. As part of the sale of the property SPMT agreed to be responsible for liabilities which are caused by or arise out of the ownership or operation of the property after April 1, 2013. SPMT is currently operating under a RCRA Part B permit with Corrective Action obligations to the USEPA. A RCRA Facility Assessment Report (RFA) was completed at the MHIC, including AOI 7 (A.T. Kearney, 1991). Several environmental investigations and interim remedial actions were completed in AOI 7 between the RFA and the RFI, as summarized in the RFI Report (GHD, 2017, revised 2019).

RFI Workplan

Evergreen submitted a Workplan for the RFI to the EPA in May 2015 (GHD, 2015). This Workplan was reviewed with the EPA on June 22, 2015. The preliminary results of the first phase of the RFI and the scope of the second phase of the RFI were presented to the USEPA on April 13, 2016, and documented in the RFI Report.

Corrective Action Framework

Evergreen worked together with the EPA between 2015 to 2017 to develop a Corrective Action Framework (CAF) under the RCRA First program. The CAF was included in the 2017 RFI (GHD, 2017/revised 2019). A copy of the CAF is included in Appendix C. The CAF was designed to memorialize a mutual understanding between the EPA and Evergreen to complete the Corrective Action (CA) obligations for the former Sunoco Marcus Hook Refinery. The CAF presented screening levels for investigations in AOI 7 including:

- Soil (Table 1a of the CAF) based on USEPA's May 2016 Industrial/Commercial Regional Screening Levels (RSL) (USEPA, 2016c&d), using a cancer risk of 10^{-6} and a hazard quotient (HQ) of 0.1 and 1,
- Groundwater (Table 1b of CAF) based on the Maximum Contaminant Levels (MCLs),
- Surface water (Table 1c of CAF) based on Delaware River Basin Commission published Water Quality Regulations (DRBC, 2013),
- Sediment (Table 1d of CAF) in Middle Creek based on USEPA Biological Technical Assistance Group (BTAG) (USEPA, 2006),
- Indoor Air (Table 1e) based on EPA RSLs and occupational exposure standards (OSHA PEL or NIOSH REL).

The CAF also laid out provisions for RCRA Corrective Action, including Corrective Action Objectives (CAOs). The EPA's CAOs for AOI 7 in the CAF were:

- Soil
 - Eliminate any direct contact exposures to soils greater than the EPA's Industrial RSL in AOI 7 (as listed in Table 2a of the CAF). These values may be modified based on site-specific risk assessment activities.
 - Mitigate exposures to LNAPL during intrusive activities by construction workers in the areas impacted by LNAPL.
 - Prevent future residential land use based on current and future use risk exposure scenarios.
- Groundwater
 - Prevent inhalation (unless further evaluated and shown to be acceptable by a vapor intrusion assessment), ingestion or dermal exposure above non-residential standards listed in Table 1b of the CAF.
 - Prohibit use of groundwater except for what is required for sampling and remediation.
 - Prevent offsite migration or discharge of LNAPL.

- Prevent offsite migration of groundwater to the Delaware River at concentrations that would exceed the DRBC fish ingestion criteria as listed in Table 2b of the CAF. The CAO was further clarified in Section VB of the CAF that the aquatic life criterion would be used if no human health criterion applied. Therefore, a value of 150 ug/l (based on the DRBC Surface Water Quality Standards – December 4, 2013) was used in developing the arsenic COA in groundwater. In accordance with Table 2b of the CAF, the selected value was then multiplied by a mixing factor for discharge into the Delaware River established by the CorMix model. The resulting CAO for arsenic in groundwater discharging into the Delaware River in the CAF was 1,500 mg/l. More details pertaining to the CorMix model is included later in this section, as well as a discussion of the proposed contingency factor to be applied to the groundwater CAO in the development of the Corrective Measure Study (CMS).
 - Prevent groundwater discharging to Middle Creek to result in concentrations exceeding the DRBC fish ingestion criteria in the Delaware River. As stated above, the CAO was further clarified in Section VB of the CAF that the aquatic life criterion would be used if no human health criterion applied. Therefore, a value of 150 ug/l (based on the DRBC Surface Water Quality Standards – December 4, 2013) was used in developing the arsenic COA in surface water.
- Surface Water
 - Prevent any impacts to the Delaware River that cause surface water concentrations to exceed the DRBC fish ingestion criteria listed in Table 1c of the CAF. The CAO was further clarified in Table 1C that the aquatic life criterion of 150 ug/l (based on the DRBC Surface Water Quality Standards – December 4, 2013) would be used in developing the arsenic COA in groundwater.
 - Prevent unacceptable ecological impacts to surface water in Middle Creek as determined by an ecological risk assessment.
 - Sediment
 - Prevent unacceptable ecological impacts to sediment in Middle Creek as determined by an ecological risk assessment.

The CAF also stated that, *“Middle Creek surface water and sediment, as well as soils and groundwater in AOI 7, may be impacted by off-site groundwater, historical overland flow, sediment transport or historic operations from the adjacent Delaware Valley Works (DVW) which is the former Honeywell and General Chemical Site. Pesticide constituents (e.g., DDT and BHC isomers) have been identified in soil, groundwater, surface water and sediment of the Marcus Hook Industrial Complex; these constituents were not used or stored at the Property. Data from the off-site locations will be reviewed to determine how off-site impacts will be incorporated into the RFI. Consequently, pesticide constituents will be included in screening of the data collected in AOI 7 but will not have corrective action objectives since they are due to off-site impacts.”*

The CAF also summarized the interim and final measures that have been completed at the MHIC. The interim and final measures included in the CAF pertaining to AOI 7 include:

- Two basins located to the north of Middle Creek in AOI 5/7 are SWMU 23 (Old Sludge Basin) and SWMU 24 (Old Decant Basin). These basins have been stabilized through the addition of fly ash and chemical treatment (addition of permanganate) as part of interim measures.
- The Middle Creek Drainage System (SWMU No. 96) was closed under RCRA in 1995. Post Closure sampling is currently being performed in select wells. The portion of Middle Creek in AOI 7 is downstream of the Final Measures completed for Middle Creek.

RCRA Facility Investigation

The RFI was completed between 2015 and 2017. The RFI was submitted in June 2017, and revised February 2019 (GHD, 2017, revised 2019). The RFI was designed to characterize soil, groundwater, surface water and sediments in accordance with the provisions of the CAF agreement with the EPA for MHIC. 70 soil borings were completed and 29 additional monitoring wells were installed during the RFI. Sampling activities included 117 soil samples from 77 locations, two rounds of groundwater samples from 44 monitoring wells, and one seep sample collected from the east side of the downstream segment of Middle Creek. Three rounds of surface water samples and two rounds of sediment samples were collected from 10 locations in Middle Creek. In addition, a tidal study was completed in Middle Creek, Delaware River and AOI 7 groundwater. A surface water mixing zone modelling study using CorMix was also completed to assess groundwater discharge into the Delaware River. The RFI also included a Human Health Risk Assessment (HHRA) and a Screening Level Ecological Risk Assessment (SLERA).

The RFI provided the following conclusions in relation to each media of investigation:

- **Soil** – Soil concentrations for Site-related constituents met the CAOs and individual locations of exceedances were well delineated by adjacent data. The results of the HHRA indicate that there are no unacceptable reasonable maximum exposure (RME) cancer risk or non-cancer HI estimates for human exposure at or around AOI 7 under current or potential future land uses.
- **Groundwater** - Groundwater concentrations in all monitoring wells were detected below the groundwater CAOs with the exception of DDx, alpha BHC and beta BHC in monitoring wells influenced by off-site impacts (adjacent DVW Site). Arsenic was evaluated as a groundwater flux to assess attainment of the groundwater CAO. Based on this evaluation, the arsenic concentrations in groundwater in the discharge zone to the Delaware River were identified in attainment of DRBC criteria.
- **Surface water and sediment** - A SLERA was completed to evaluate surface water and sediment conditions in Middle Creek. The SLERA identified no unacceptable risks to ecological receptors from Middle Creek sediment and surface water. Only samples from the most downstream stations in Middle Creek had concentrations of DDx or arsenic exceeding the values developed by Environ on behalf of Honeywell for its sediment corrective actions in Middle Creek. Since these impacts were not attributed to former Sunoco operations, no further action was warranted for Middle Creek.

The findings of the RFI were that soil and groundwater at AOI 7 have been impacted by both Site-related and historic deposition of non-Site related constituents of concern. Arsenic was found in groundwater above the CAOs in a very limited area in the southwestern corner of AOI 7. Arsenic was also detected in sediments in the same area (which is the downstream portion of Middle Creek). The RFI concluded that there were no known current or past uses of arsenic at the Site that were the source of the observed arsenic concentrations in the southwestern portion of AOI 7. Upon review of historic operations, historic aerials and data collected for the DVW facility, it was concluded that the source of the arsenic in the southwest corner of AOI 7 was due to historical deposition from operation of SWMU 9 and potentially due to ongoing groundwater discharge from SWMU 9.

Specifically, the RFI recommended that a CMS be completed to further evaluate the AOI 7 related soils and groundwater that exceeded the CAOs, including the development of a groundwater monitoring program to assess ongoing groundwater quality in relation to the CAOs and to develop a decision-making process for corrective action, if appropriate, to protect surface water quality. Discussions with the EPA in relation to the CMS, following the submittal of the RFI, included the inclusion of a contingency screening level, an order of magnitude lower than then established groundwater CAOs for groundwater discharging to the Delaware River, for the CMS. This contingency screening was not proposed to be applied on a well-by-well basis, but rather to be based on groundwater flux. The RFI recommendations assumed that the corrective action for sediments in Middle Creek for arsenic and pesticides would be addressed by the proposed corrective action program for DVM.

November 2017 EPA Correspondence

The November 2017 EPA correspondence in response to the RFI suggested additional items to be completed by Evergreen to assist in the remedial efforts ongoing at the adjacent Delaware Valley Works/General Chemical Corporation/Honeywell Facility including; confirming arsenic concentrations in groundwater, characterization of arsenic in sediments and porewater, estimating mass flux of arsenic from groundwater to the Delaware River, estimating mass loading of arsenic from Middle Creek to the Delaware River. The following is a brief summary of Evergreen's January 2018 response to the EPA's November 2017 correspondence (Evergreen's response is included in Appendix C).

- The elevated arsenic concentrations along the Delaware River in MW-560, MW-531L and MW-532L were attributable to deposition from historic operations at the adjacent DVW facility. However, Evergreen planned to complete additional groundwater sampling as part of the CMS development (once the RFI was approved).
- Arsenic was characterized in sediments in Middle Creek, as well as being assessed through an ecological risk assessment. In the ecological risk assessment, the arsenic results were evaluated against the alternative sediment benchmark (PRG) developed by Environ 2012 which was 300 mg/kg in Middle Creek. Two locations at the mouth of Middle Creek did have some exceedances of that PRG due to offsite impacts from DVW. The ecological risk assessment evaluated these results in context with the rest of the sediment and surface water results in Middle Creek and it was determined that there

was no unacceptable risk due to arsenic in the sediments in Middle Creek as summarized in the RFI. Since there is no unacceptable risk from the sediments as well as the groundwater that was discharging into Middle Creek, there was no need to for Evergreen to collect either sediment or porewater samples.

- The RFI established the groundwater flux discharging to the Delaware River. Twenty-two wells within 300 feet of the Delaware River and 15 wells along Middle Creek were used to evaluate groundwater flux. Evergreen's January 2018 response stated that based on the information in the RFI, the calculated mass flux to the Delaware River was 0.012 lb/day. Since the ecological risk assessment of Middle Creek did not identify an unacceptable risk, no additional sediment loading evaluations were necessary to be completed during the RFI for AOI 7.

The EPA responded in an April 2018 correspondence, which is include in Appendix C, that they agreed with and accepted Sunoco responses in their November 2017 letter, and that Evergreen did not need to complete porewater or sediment sampling to assist in the design of Honeywell's remedial activities. The letter did state that the EPA was performing its own assessment and would inform Evergreen if further activities would be required.

CorMix Modeling Correspondence

The EPA and Evergreen had correspondence between 2017 and 2018 relating to the assumptions in the CorMix model and use of AVS/SEM as presented in the RFI. Since the EPA was satisfied with Evergreen's responses concerning AVS/SEM and this subject does not pertain to the IM Workplan, AVS/SEM is not discussed further in this summary. The following briefly summarizes the correspondence in relation to the CorMix model since that does pertain to the IM Workplan.

- Evergreen submitted a March 2017 Technical Memorandum which presented the approach for using CorMix for the AOI 7 RFI (GHD, 2017). This Technical Memorandum was included in the 2017 RFI.
- The EPA had additional questions concerning the CorMix model summarized in email correspondence from January to March 2018, which is included in Appendix M of the 2019 RFI (GHD, 2019). Specifically, The USEPA correspondence identified specific sections of the Delaware Surface Water Regulations (<http://regulations.delaware.gov/AdminCode/title7/7000/7400/7401.shtml>) that they requested Evergreen provide more detail on how the proposed approach using the CorMix model would address the requirements of the Delaware Surface Water Regulations. Evergreen provided a June 2018 Technical Memorandum providing more information for each of the specific sections of the regulations identified by the EPA in their March 8, 2018 EPA correspondence. The conclusions of Evergreen's June 2018 memorandum supported the use of a mixing zone in accordance with the Delaware regulations and as presented in the RFI.
- Based on subsequent conversations with the USEPA in December 2018, Evergreen made revisions to March 2018 Technical Memorandum, including updating the CoreMix modeling completed for AOI 7 and resubmitted the Technical Memorandum in a revision to the RFI (GHD, 2019). These revisions expanded the mixing zone and clarified the use of the 1000:1 factor used to develop a conservative contingency or trigger level

for the CMS (as discussed above in relation to the RFI conclusions). None of these revisions changed the proposed CAO in groundwater. This Technical Memorandum did identify arsenic concentrations in the groundwater that exceeded an acute aquatic life screening criterion, in the immediate vicinity of the groundwater seepage, but the DRBC criteria were met based on the groundwater flux assessment and within the mixing zone.

2019 to 2021 Correspondence

Evergreen contacted the EPA in December 2019 to discuss EPA approval of the RFI and moving forward with the CMS. The EPA and Evergreen then met in June 2020 and October 2020 to discuss the EPA's request for additional information from Evergreen supporting that the arsenic concentrations in the southwestern corner of AOI 7 were not due to former Sunoco operations. Evergreen responded with a December 2020 correspondence which reiterated the findings of the RFI and that there is not a historical source for arsenic as part of the Sunoco operations, but proposed additional investigation activities to respond to the EPA's requests. The EPA responded with a March 17, 2021 letter requiring additional investigation beyond what was proposed in Evergreen's December 2020 correspondence. Evergreen responded in an April 13, 2021 correspondence with an expanded scope of work, but with additional supporting information that the original source of the arsenic was not former Sunoco operations. Evergreen also had teleconferences with the EPA in April 2021 to discuss the proposed scope and path forward. Evergreen completed additional groundwater sampling and surveying in May 2021 and proposed additional work in email correspondence in May 2021. Appendix C contains the correspondence between the EPA and Evergreen in 2020 and 2021. Evergreen then received the EPA's June 23, 2021 request for an IM Workplan and additional investigation. Evergreen reviewed the proposed scope of work with the EPA in July 2021 and began field work on July 13, 2021.

AOI 7 Summary

Evergreen has completed significant investigations in AOI 7, collecting soil and groundwater samples throughout the shallow and deep intervals, characterizing sediment and surface water in Middle Creek and completing a HHRA and SLERA. The results of these investigations characterized environmental conditions in AOI 7 and identified arsenic impacts in the southwestern corner of AOI 7, immediately adjacent to SWMU 9. A historic source due to Sunoco operations for the elevated arsenic observed in groundwater and soil in the southwestern portion of AOI 7 was not identified, however, historic sediment deposition from the operation of SWMU 9 into the southwestern corner of AOI 7, before it was filled by Sunoco to create land, was identified as the source of arsenic (and pesticides) in AOI 7. Potential migration of groundwater with elevated arsenic concentrations from SWMU 9 to AOI 7 was also identified based on the activities completed prior to the IM Workplan

2.2 SWMU 9/South Plant

The Honeywell DVW is a former chemical manufacturing plant which manufactured chemical products including pesticides, organic and inorganic acids, and various other specialty chemicals (MACTEC, 2005) since the 1890s. SWMU 9 was used for disposal of pesticides and related wastes, arsenic, materials from pesticide production, and laboratory

samples disposal. SWMU 9 historically functioned as a stockpiling and dewatering impoundment for alum mud sludges from 1966 to the late 1980s in the area adjacent to AOI 7 and was constructed by placing a bulkhead along the Delaware River and placing alum mud for dewatering. SWMU 9 reportedly contains over 350,000 tons of gypsum, iron oxide sludge, and alum sludge stockpiled to heights of up to approximately 50 feet above pre-fill grades. Topographic surveys identify three distinct topographic levels within the Site (Wood, 2020). The highest elevation level [ranging from 40 to 50 feet above mean sea level (AMSL)] is located in the northwestern third of SWMU 9, the intermediate elevation level (ranging from 25 to 30 feet AMSL) is located in the south central portion of SWMU 9, and the lowest elevation level (ranging from 5 to 15 feet amsl) is located in the southernmost third of the SWMU 9 adjacent to the Delaware River and along the sluiceway and Middle Creek sides of SWMU 9.

In September 2011, EPA issued an Administrative Order to Honeywell International Inc. pursuant to Section 3008(h) of RCRA which required a facility-wide investigation of the DVW facility. The requirements of the order included (i) interim measures/stabilization to control groundwater release and control human and ecological exposure; (ii) an RFI to provide more detail on the SWMUs; and (iii) a Corrective Measures Study (CMS), if warranted, to propose final cleanup actions needed. The South Plant portion of the DVW facility received a Statement of Basis specific to the contaminated soils at the South Parcel from USEPA for RCRA Corrective Action in 2016 (USEPA, 2016a).

The following briefly summarizes the environmental history for SWMU 9 as it relates to the AOI 7 IM Workplan. The majority of the sampling activities only analyzed samples for metals and pesticides. As a result of investigations on the DVW property, sediment investigations extended down the sluiceway and into the Delaware River. In its investigation of sediments in the Delaware River, Honeywell identified arsenic, lead and DDx as key constituents detected and concentrations of potential concern. More detailed information is summarized in Wood, 2020 and other reports included in the Section 11.0.

2003 RFI

A Phase 1 and II RFI was completed in 2003. The phase 1 RFI consisted of the installation of 18 soil boring, collection of 16 soil samples, collection of three grab groundwater and three surface water samples. The phase II RFI consisted of installation of six shallow wells with related groundwater sampling. The Phase II RFI also included a hydraulic conductivity study. The results of the RFI was reported in MWH Americas, 2007.

2008 EPA Investigation

In 2008, EPA collected Delaware River sediment samples within the tidal mudflats, adjacent to the former South Plant and SWMU 9. The sampling data indicated the presence of pesticides (primarily DDT and its isomers) and several metals (primarily arsenic and lead) (Cummings/Riter Consultants, Inc. 2010).

2010 Investigation

In 2010, surface soil and groundwater samples were collected from the Site to address data gaps from earlier investigations. The results of the 2010 Investigation were included in the RFI Workplan (AMEC Foster Wheeler, 2015)

2012 Development of PRGs

Environ, on behalf of Honeywell, presented a set of proposed preliminary remediation goals (PRG) for DDX, arsenic and lead in sediment in the Delaware River and Middle Creek based on the investigations completed at the DVW Site (Environ, 2012). Sediment PRGs for arsenic were recommended at 130 to 170 mg/kg in the Delaware River and at 300 mg/kg in Middle Creek. Evergreen proposed revised lead PRGs in the RFI (GHD, 2017), which were accepted by the EPA.

Environ also presented a preliminary derivation of a screening value for arsenic in groundwater that may have the potential to migrate from the Delaware Valley Works site located in Claymont, Delaware to the sediment-water interface in the adjacent Delaware River in the July 2017 *Technical Memorandum: Groundwater Screening Value for Arsenic to Protect Sediment Pore Water* (Environ, 2017). The report stated that arsenic in groundwater is not expected to cause adverse effects to organisms residing in the river due to dilution and mixing of groundwater with surface water, as indicated by direct sampling of surface water at the site. The reason given for the development of the arsenic groundwater PRG was concern from the USEPA regarding the potential for adverse effects from arsenic in sediment pore water (originating from groundwater) on benthic organisms residing in the cap (Environ, 2017).

Aquatic toxicity data for arsenic were evaluated to assess arsenic groundwater concentrations that may have the potential for adverse effects on benthic organisms at the Claymont site. Sources considered in this evaluation include data underlying the saltwater chronic national recommended water quality criterion (NRWQC) of 36 ug/l and additional aquatic toxicity data identified from the USEPA's online ECOTOX database (USEPA 2017). The arsenic groundwater PRG (1,253 ug/l) was developed to protect the most sensitive benthos receptor (based on data for the polychaete worm, *Capitella capitella*) using a chronic exposure in a saltwater environment. It was proposed as a only a screening value based on the conservative way it was derived and that it didn't not consider attenuation along the groundwater pathway or groundwater flux. The arsenic groundwater PRG was developed for the DVW site, by Honeywell, without the opportunity for Evergreen to review or comment, therefore the application of this arsenic groundwater PRG to AOI 7 is not appropriate until it is further evaluated for the AOI 7 Site.

2012 through 2017 Honeywell Investigations

Honeywell collected Delaware River sediment samples in 2012, 2015 and 2016. The results of this sediment sampling indicated detections of DDX and arsenic above the PRG. These investigations were discussed in the following reports:

- Delaware River Sediment Sample Collection (October 2012),

- Evaluation of Sediment Remediation Goals (2012),
- Sediment Sampling and Analysis Results (August 2015),
- Supplemental Study Area Sediment Investigation Workplan (July 2016), and
- Supplemental Study Area Sediment Investigation Report (February 2017).

2015 RFI and 2018 Supplemental Investigations

The RFI activities included geotechnical evaluation and installation of one monitoring well (AMEC Foster Wheeler, 2016). An additional geotechnical investigation was completed in 2018 and reported in Wood 2019a.

2017 Supplemental Sediment Study Area Sediment Investigation Workplan

Honeywell proposed additional sediment delineation in front of AOI 7 in the 2017 Workplan. This Workplan highlighted that the sediment in front of AOI 7 is dredged depths range from within the berth areas range of 20 feet at the inner docks to approximately 40 feet at the outer docks (USACE, 2001).

2017 Supplemental Study Area Sediment Investigation Report

The supplemental investigation was performed to complete the delineation of impacted surface sediments to the east of the DVW site, in front of AOI 7. The sediment samples were analyzed for DDX and were successfully delineated to the East. This report also identified the extent of the proposed cap in front of AOI 7 to address DDX in sediments (Ramboll, 2017).

2017 Supplemental Pathway Investigation

Conducted by Anchor QEA, LLC on behalf of Honeywell to assess the fate of arsenic in groundwater potentially discharging to nearshore sediments of the Delaware River through sampling and characterization of arsenic, arsenic speciation, anions, cations, alkalinity, sulfide and metals (dissolved and total) in surface water, groundwater, porewater and surficial sediments (not every media or sample had all of these analytes). Sediment samples were also analyzed for sequential selective extraction (SSE). SSE is a method that provides detailed information regarding the solid phase associations of arsenic which would not be available to ecological receptors. This investigation also collected geotechnical cores from the sediment to evaluate the physical properties of nearshore sediments and slug tests in wells to determine hydraulic conductivity. This investigation identified some significant findings to be considered in relation to the AOI 7 IM Workplan.

- At many locations porewater samples were not able to be collected due to insufficient flow/volume and clogging of the filter with fine sediments. This supports that there is very low groundwater flux through the sediments at many of the sampled locations
- Sediment diagenetic processes involving the transformation of As(V) to As(III) and production of sulfides in the reducing environment of the fine-grained, organic-rich sediments, ultimately result in 99% or more of the arsenic being bound to sediment solid phases, including iron and arsenic sulfides sorption.

- The strong sequestration of arsenic in sulfide phases within sediments indicates sediment is a net sink of arsenic at the site and is expected to continue to act as such as long as sulfate is available to sustain microbial sulfate reduction.

2019 Supplemental Investigation

In 2019, six soil borings were advanced in the southeastern portion of the SWMU 9 for the collection of soil samples and the installation of four monitoring wells (two shallow and two deep) between the Site and AOI 7 as reported in Wood, 2020. The shallow wells were screened to be consistent with AOI 7 shallow wells. The deep wells were installed in “strata four” beneath SWMU 9, which was a sand and gravel layer beneath the silty clay, and not specifically installed in the same lithology as the deep wells in AOI 7, as discussed in the 2019 SWMU 9 Supplemental Workplan (Wood, 2019).

2019 DVW Pore Water Sampling Event

Conducted by the US Army Corps of Engineers (USACE) that analyzed arsenic and pesticides in shallow and deep porewater in the Delaware River immediately adjacent to the SWMU 9 and AOI 7 boundaries. This sampling identified elevated arsenic in porewater and sediment in front of the South Plant and AOI 7. (USACE, 2019)

2020 SWMU 9 Data Summary Report

An RFI Data Summary Report for SWMU 9 was prepared for EPA to summarize data collected to date for that site (Wood, 2020).

SWMU 9 and South Plant Summary

There has been relatively limited collection of soil and groundwater analytical data within SWMU 9 and the South Plant, especially in comparison to sediment and surface water data collection efforts. Instead, many of the studies within SWMU 9 have been focused on geotechnical data collection, due to the presumptive capping remedies for SWMU 9 (Wood, 2020). Therefore, while documented arsenic waste has been reported in SWMU 9 and elevated arsenic soil concentrations have been observed, additional characterization of the silty clays consistent with the geologic unit the deep wells in AOI 7 are screened may still be a data gap for SWMU 9.

3.0 ENVIRONMENTAL SETTING

Section 3.0 presents the environmental setting for AOI7 and the surrounding area. This environmental setting is based on the data collected both in AOI 7 and SWMU 9, including the recent data collected by Evergreen in May through August 2021 which was collected as part of the IM Workplan activities.

3.1 Topography and Hydrology

The highly modified and channelized Middle Creek served as conveyance for containment and transport of both local stormwater and process wastewater until the early 1990s when the majority of Middle Creek became contained in a conveyance system. Surface water now

mostly travels through an open concrete channel, roughly following the Middle Creek beds, and process waste is conveyed within enclosed piping upstream of AOI 7. Currently, an unlined remnant of Middle Creek exists to the southwest of the concrete dam located in the vicinity of the Middle Creek Interceptor Trench Recovery System in AOI 5 and then travels through AOI 7 and connects to the Delaware River at the southwestern corner of AOI 7. The location of Middle Creek is shown on Figure 3.

Topography in AOI 7 was naturally low lying coastal plain prior to development in the early 20th century. Figure 5 shows the locations of historic streams and marshes circa 1898 within the facility. In this figure, Walker's Run, a former perennial stream, daylights as a spring at the slope located just to the north of Ridge Road. This northeast/southwest trending portion of Walker's Run is what would later be referred to as "Middle Creek". An additional stream (called Bear Creek) is also noted to have existed to the west of current Blueball Road and merged with Walker's Run near its confluence with the Delaware River at a point near the state line as shown on Figure 5.

The course of these surface water features was altered throughout the development of the former refinery, which involved channelization and straightening of the creek's path and movement of its mouth to the west within AOI 7. Figure 5 and the historical maps in Appendix B depict the course of the natural streams in 1898 and the relocated channels described below. Approximately 60 percent of the area of AOI 7 was originally low lying, being either under the Delaware River (and later reclaimed) or in a marsh area adjacent to the natural Middle Creek. These low-lying areas were reclaimed by the placement of fill to raise the ground surface above the Delaware River and provide a stable base for subsequent development. A sheet pile bulkhead exists along a portion of the AOI 7 boundary with the Delaware River.

3.2 Regional Geology

The MHIC is located on the up-dip edge of the Coastal Plain Physiographic Province near its contact with the Piedmont Physiographic Province. The Coastal Plain is characterized by relatively low topography and is underlain by unconsolidated deposits of mud, sand, and gravel-sized materials. Within the Coastal Plain, sedimentary deposits generally decrease in thickness and "pinch out" against crystalline bedrock of the Piedmont along a transition zone referred to as the "Fall Line", which is located along the northern boundary of the facility. The Coastal Plain consists of a seaward-thickening, wedge-shaped sequence of sedimentary deposits that accumulated in a variety of marine and non-marine environments. Defined geologic units/formations of the Coastal Plain outcrop and subcrop at the facility and generally strike northeast/southwest, dip to the southeast, and overlie a deepening bedrock surface.

According to published geologic maps for the Site, sedimentary deposits of the Coastal Plain near the facility are Quaternary in age (Pleistocene and Holocene). In Pennsylvania, the Coastal Plain sediments are identified as belonging to the Quaternary Trenton gravel, which is generally present between sea level and 40 feet AMSL (along a river terrace) with local thicknesses that are commonly less than 20 feet (Balmer & Davis, 1996). The Trenton gravel is discontinuous in aerial extent, variable in vertical thickness and range of

elevation, and primarily consists of gravelly sand interstratified with semi-consolidated sand (limonite-cemented) and clay-silt beds (Owens & Minard, 1979). The Trenton gravel is commonly gray or pale reddish brown in color. In Delaware, Quaternary deposits are identified as undifferentiated Delaware Bay Group (upper Pleistocene) consisting primarily of sandy alluvium but with secondary lithologies including silty clay, peat, and sandy gravel in thicknesses up to 20 feet (Ramsey, 2005).

According to the Bedrock Geology Map of the Piedmont of Delaware and Adjacent Pennsylvania (Plank, Schenck & Srogi, 2000), bedrock beneath the facility is of the Wilmington Complex. The Wilmington Complex consists of metamorphosed igneous rocks including meta-volcanic units, meta-plutonic units, and un-deformed plutons. More recently in 2008, Bosbyshell published an updated bedrock geologic map that included mapping of the facility area.

3.3 MHIC Geology

Although the subsurface conditions above bedrock at the facility are locally heterogeneous, the geologic framework underlying the facility can be grouped into three general units. The uppermost unit is anthropogenic fill, which generally covers the entire surface of the facility to varying depths. Underlying the fill is recent alluvium consisting primarily of silty clay which may have been deposited in estuarine environments of the Delaware River or a tributary, such as Middle Creek. The third unit includes unconsolidated sands and gravels with silt and clay, which fits published descriptions of the Trenton gravel (or adjacent Delaware Bay Group in Delaware).

Fill has been reported to be present underlying the entire facility at variable extent and thickness ranging from approximately 1 to 25 feet; however, fill is thicker in areas where reclamation extended into the Delaware River, such as in AOI 7. The fill composition varies, but generally is composed of one or more of the following: silt, sand, gravel, clay, wood fragments, cinders, apparent dredged material, sludge, spent clay, and other construction/demolition or refinery materials. Portions of the facility that extend beyond the historic Delaware River shoreline of 1937 were generated by filling of the Delaware River margin with various refinery-generated materials.

Underlying the fill unit are silty clay sediments, hereafter referred to as the silty clay layer. The silty clay layer within the facility consists of micaceous, greenish-gray silty clay with minor roots, wood, peat, and other vegetative material, but can vary to include interbedded fine-grained sands, silty sands, clayey silts, and gravels. The light to dark gray silty clay is generally soft but can become stiff with depth or where there are sandy soils. The lithology of the silty clay layer is consistent with what Owens & Minard (1979) describe as Delaware Bay estuarine deposits, organic-rich estuarine facies consisting of dark colored clayey silts interbedded with fine to very fine sand. The silty clay layer is present beneath most of the facility and thickens towards the east and the historical shoreline of 1953 in AOI 7. Beneath the facility, the silty clay layer ranges in thickness from approximately 5 to 20 feet.

Apparent Trenton gravel deposits underlie the silty clay layer and unconformably overlie bedrock at the facility. The Trenton gravel generally ranges in thickness from

approximately 2 to 10 feet. The Trenton gravel consists of fine to coarse-grained sand, gravel, sandy silt, and clayey sand. The sand and gravel unit is present throughout much of the facility; however, its thickest deposits vary laterally. The sands and gravels commonly coarsen with increasing depth. Cobbles may be present atop bedrock in some areas of the facility, generally along the shoreline of the Delaware River.

Bedrock at the facility has been identified through test boring advancement. Where encountered, a saprolite layer is common that contains a visible rock fabric consistent with published descriptions of Ardentown Granitic Suite crystalline bedrock. Along the northern facility boundary, bedrock was identified near surface beneath a veneer of a few feet of fill. The bedrock surface slopes south and deepens towards the Delaware River. The elevation of the top of crystalline bedrock (including saprolite) at the facility ranges from approximately 30 feet to deeper than -50 feet NAVD 88.

3.4 AOI 7 Geology

The AOI 7 geology is based on borings/monitoring well installations completed as part of the RFI as well as those completed during additional activities completed in July 2021. No pyritic waste was observed during completion of the RFI or the July 2021 borings. Permanganate was observed during the RFI and July 2021 in soils, as summarized on Table 1. Permanganate injections were completed as an interim remedy for SWMU 23/24 prior to the RFI. Light non-aqueous phase liquid (LNAPL) was also observed during installation of the July 2021 borings/monitoring wells and are also summarized on Table 1. The boring logs from the July 2021 activities, which are included in Appendix D, also summarize the observations of permanganate or LNAPL. LNAPL was also observed during the RFI (GHD, 2017, revised 2019),

The geologic units described in Section 3.3 for the MHIC, are also present in AOI 7. These units consist of fill underlain by a silty clay, underlain by sands and gravels (Trenton Gravel), underlain by bedrock. A cross-section location map is included as Figure 6 and the AOI 7 geology is shown on Figure 7 (East – West, cross section A-A' along the Delaware River) and Figure 8 (North – South, cross section B-B' along Middle Creek). None of the borings in the RFI or the July 2021 investigations were completed to bedrock. Due to the history of filling with AOI 7, the AOI 7 geology is presented in relation to the 1953 shoreline to provide more detail to each portion of AOI 7 geology.

North of the 1953 fill line

The following summarizes the geology within AOI 7, north of the 1953 shoreline (descending in elevation):

- Fill – ranges from 4 to 10 feet thick. The fill material consists of clayey silt with gravel, bricks, concrete, wood fragments, and organic material.
- Silty Clay - ranges from 6 to 20 feet thick. The silty clay is described as a dark gray/brown/green clayey silt or silty clay.
- Sand and Gravel - ranges from 1 to 2 feet thick. The sand and gravel is described brown Sand with varying amounts of silt and little gravel.

South of the 1953 fill line

The following summarizes the geology within AOI 7, south of the 1953 shoreline (descending in elevation):

- Fill – ranges from 20 to 25 feet thick. The fill consists of top layer approximately consisting of brown silty sand, clay and gravel with some brick debris, glass, rock fragments, and organic material, which is underlain by silty clay or clayey silt with varying amount of sand. The bottom of the fill unit is difficult to distinguish from the underlying silty clay or clayey silts, but is shown as a separate unit on cross sections (Figures 7 and 8).
- Silty Clay ranges from 2 to 10 feet thick. The silty clay is described as brown, gray silty clay or clay and appears to represent the top Delaware River sediments, before the area was filled. Due to the nature of the filling this unit is mixed at locations with the overlying fill.
- Sand and Gravel - ranging from 2 to 4 feet thick. The Sand and Gravel is described as gray, brown sand with silts and gravel.

3.5 SWMU 9 Geology

As summarized in Wood, 2020, the results of the 2018 Geotechnical Investigation (which generally supported previous geologic interpretations) described the geology of SWMU 9 as follows (descending in elevation):

- Fill material
 - Stratum 1, Waste Fill, predominantly alum mud, a reddish brown and light gray silt-size material.
 - Stratum 2, Industrial Fill, consisting of various landfilled materials such as glass shards, scrap metal, and wood fragments.
- Native material (underlying the fill):
 - Stratum 3, Silt/Clay, an organic silt becoming gray and brown silt or clay; and
 - Stratum 4, Sand and Gravel.

Figure 7, cross section A to A', utilizes the borings logs and elevations from SWMU 9 as well as Figure 4 (Cross Section A to A') from the Supplemental Pathway Investigation Results Report (AMEC, 2017) to depict geology in SWMU 9.

3.6 Hydrogeology

In southeastern Pennsylvania, unconsolidated sands and gravels of the Coastal Plain and fractured crystalline bedrock of the Piedmont can function as aquifers where saturated and sufficiently permeable. Crystalline bedrock, particularly igneous and high-grade metamorphic rock types such as those associated with the Wilmington Complex, generally has low porosity with little, if any, secondary porosity/permeability yielding poor water-producing capabilities. Near the MHIC, these rocks have been described to yield too little water for industrial or public water supply (Balmer & Davis, 1996) and have a median well

yield of less than 10 gallons per minute (gpm) (Bosbyshell, 2008). Where unconsolidated Coastal Plain sediments are present at the land surface, these rock types have been further described to "serve chiefly as a lower confining layer to retard movement of water of the overlying aquifers" (Greenman, Rima, Lockwood, & Meisler, 1961). Balmer & Davis (1996) provide a median yield of 50 gpm for wells screened in the Trenton gravel in Delaware County. However, transmissivities may be limited due to that deposit's small, saturated thickness and local-scale heterogeneity. Recent alluvial deposits, including the Delaware River Estuarine silty clay and the Trenton gravel, are not expected to represent a significant potable water source in eastern Delaware County based on potential saline/brackish water impacts from the Delaware River (Balmer & Davis, 1996). The MHIC and the surrounding areas are served by public water supply and river water intakes.

At the MHIC, monitoring well data indicates that groundwater can occur in areas of fill, the silty clay layer, and/or Trenton gravel units at depths ranging from approximately 1 to 20 feet (ft.) below ground surface (bgs). Groundwater generally occurs within these strata under unconfined conditions as one continuous water-bearing unit (e.g., water-table aquifer), and groundwater elevations generally decrease towards the shoreline of the Delaware River. However, perched groundwater can occur within the fill layer where the fill is present atop the silty clay layer, and where the top of the silty clay layer is above the regional zone of saturation.

3.6.1 Tidal Influences in Middle Creek and Delaware River

Both the Delaware River and Middle Creek are tidally influenced surface water bodies. Groundwater elevations along the tidal Delaware River appear to be influenced by semidiurnal tides, with maximum groundwater fluctuations of approximately 1 to 2.7 feet immediately adjacent to the Delaware River and 0.1 to 0.15 feet approximately 300 feet inland (GHD, 2017). A tidal study completed as part of the RFI showed the effects of tidal stage in the Delaware River on groundwater elevations were significant along the Delaware River, but were diminished at a distance of 250 feet from the river (e.g., as seen in MW-533U), as shown in Figure 9. It should be noted that the elevations shown on Figure 9 was to a local plant datum.

3.6.2 AOI 7 Hydrogeology

The AOI 7 hydrogeology is based on groundwater information collected during the RFI as well as activities completed between May and August 2021. Two groundwater units, shallow and deep, have been characterized within AOI 7. Both the shallow and deep groundwater units are unconfined and are interconnected. Generally, the shallow monitoring wells are screened in the fill unit and the deep monitoring wells are screened in the deeper fill, silty clay or sand and gravel units, depending on their location in AOI 7. Table 2 summarizes the groundwater elevations collected between May and August 2021. Groundwater recovery is associated with two remediations systems in AOI 7, which include fluids recovery as part of the Middle Creek remediation system and the remedial system associated with Phillips Island in AOI 5, located along the eastern boundary of AOI 7. The wells in these systems are noted on Figure 3. The effects of these systems are very localized and do not impact groundwater flow in either shallow or deep groundwater units.

A vertical gradient exists between the shallow and deep groundwater units, as summarized in Table 3 and shown on Figure 10. The vertical gradient is upward along the Delaware River on the Eastern portion of AOI 7. The vertical gradient is downward for the remainder of AOI 7, as shown on Figure 10. Also observed during the well installation of MW-558D was the presence of a wooden structure assumed to be the wooden bulkhead used to contain the alum mud during the construction of SWMU 9, as shown in historical aerials. Wood was encountered to 18 feet below grade at this location. Due to this obstruction, MW-558D was constructed as a 1-inch monitoring well to allow the well to be installed. This feature is shown on Figure 7 and is assumed to influence shallow groundwater flow in this area.

The groundwater contours shown on Figures 11 and 12 are based on the August 2021 groundwater monitoring event which included all the AOI 7 wells, selected SWMU 9 wells and the staff gauges in Middle Creek. Groundwater elevations in the shallow groundwater unit in both AOI 7 and SWMU 9 are approximately 1 to 2.5 feet above mean sea level (AMSL), adjacent to Middle Creek and along the Delaware River. As seen in Figure 11, mounding is observed in shallow groundwater elevations from approximately 4 to 8 ft AMSL in the central to southern portions of AOI 7. Also seen in Figure 11, groundwater flows radially from this high in the center of AOI 7, towards the Delaware River, Middle Creek and to the east-northeast towards AOI 5. The contours also indicate preferential groundwater pathways in AOI 7 correlating with the 1953 location of Middle Creek (Figure 5). Other localized mounding is also observed in selected AOI 7 wells (MW-53 and MW-565S), as noted on Figure 11, based on water seepage from nearby fire water lines. Shallow groundwater flow in SWMU -9 is towards the Delaware River and Middle Creek, as shown on Figure 11.

Groundwater elevations in the deep groundwater unit are approximately 1 to 2.5 feet AMSL adjacent to Middle Creek and 2 to 3 ft AMSL along the Delaware River. As seen in Figure 12, mounding is also observed in deep groundwater elevations from approximately 4 to 7 ft AMSL in the center of AOI 7 coincident with historic filling of Middle Creek. Also seen in Figure 12, deep groundwater flows towards the Delaware River and Middle Creek. The contours also indicate slight preferential groundwater pathways correlating with the 1953 location of Middle Creek (Figure 5). Other localized mounding is also observed at one location (MW-565D), as noted on Figure 12, based on water seepage from nearby fire water lines. Deep groundwater flow in SWMU -9 is towards the Delaware River with localized flow along the eastern border towards AOI 7, as shown on Figure 12.

As shown on Figure 11 and 12, the surface water elevation in Middle Creek is 3.5 to 3.66 ft AMSL, which is approximately 2 feet higher than the adjacent groundwater elevations. This elevation collected in August 2021, was at mid to high tide. Flow in Middle Creek is very variable, with a tidal range of up to 6 feet. Evergreen surveyed the elevation of Middle Creek bed surface in May 2021 as is summarized on Table 4 and shown on Figure 7. The elevation of Middle Creek bed is generally within the screened interval of the shallow wells and above the screened interval of the deep wells.

The depth to water in the wells located along the Delaware River in AOI 7 range from 7 to 16 feet below ground surface, which is consistent with the fact that the ground surface is

elevated due to filling by approximately 15 feet. Overall groundwater flow in the vicinity of Middle Creek is expected to be toward Middle Creek. As shown in Figure 11, Middle Creek is expected to separate shallow groundwater flow in AOI 7 and SWMU 9. As shown in Figure 12, there is a component of flow in the deeper groundwater that is expected to go beneath Middle Creek. Groundwater flow in the vicinity of the Delaware River is expected to be towards the river, as shown in Figures 11 and 12.

3.6.3 LNAPL

As shown on Figure 13, LNAPL was observed in 14 monitoring wells in AOI 7 with apparent thickness ranging between approximately <0.01 and 8.96 feet during the August 2021 field events. There was limited LNAPL observed in the vicinity of the operating recovery systems (Phillips Island Control System). More LNAPL was observed within AOI 7 during the 2021 investigation than was observed during the RFI, which is expected due to aged and weathered nature of the LNAPL which results in very limited LNAPL transmissivity, so it would take a long time for LNAPL to accumulate in monitoring wells.

3.7 SWMU 9 Hydrogeology

As presented in Wood, 2020, groundwater flow in SWMU 9 has been inferred to be laterally toward the discharge boundaries along the sluiceway, Middle Creek, and Delaware River. The alum mud waste (including gypsum and iron oxide sludge) was virtually impenetrable during the geotechnical investigations conducted as part of the 2015 RFI; refusal was encountered in some places at depths ranging from approximately 2 feet to 17 feet bgs and standard penetrometer tests (SPT) N-values were typically greater than 50 blows per foot in shallow fills, suggesting a hard material that may have a low hydraulic conductivity. Consequently, infiltration of precipitation and consequent recharge of the water table may not occur within portions of the SWMU 9 and may be limited to the peripheral areas of SWMU 9 where the waste thickness is the least because of the cementitious nature of the waste materials (AMEC Foster Wheeler, 2015). Because of compression dewatering of the underlying native soils caused by the mass of the waste pile, groundwater may be diverted around the alum mud. Appendix E includes the groundwater contours for SWMU 9 included in the 2020 SWMU 9 Data Summary Report (Wood, 2020) and the Supplemental Pathway Investigation Results Report (AMEC Foster Wheeler, 2017). The December 2019 shallow groundwater contours (Figure 11, Wood, 2020) shows groundwater flow towards Middle Creek and the Delaware River. The November 2016 shallow groundwater contours from the South Plant and western side of SWMU 9 shows groundwater flow into the Delaware River. The December 2019 deep groundwater contours (Figure 12, Wood, 2020) flow to east towards AOI 7.

4.0 SUMMARY OF 2021 INVESTIGATIONS ACTIVITIES

The following sections summarize the investigation activities completed in AOI 7 between May 2021 and August 2021 in response to the EPA's requests for additional work in AOI 7, as summarized in Section 1 and 2.1. The investigation activities were completed in accordance with the Scope of Work proposed in Evergreen's April 13, 2021 letter, which was modified based on EPA's comments and re-submitted on July 10, 2021 (Appendix C). Field work was performed in accordance with Evergreen's Quality Assurance/Quality

Control Plan and Field Procedures Manual (Appendix F). Analyses of samples were conducted by Eurofins Lancaster Laboratories. Laboratory analytical reports are included in Appendix G. Figure 3 shows the locations of the soil and groundwater samples collected during the 2021 investigation and these activities are summarized in Table 5.

4.1 Sampling Rationale

The following summarizes the sampling rationale for the activities completed from May to August 2021 at AOI 7 by Evergreen in response to the EPA's March 17, 2021 and June 23, 2021 correspondence.

- A groundwater sampling event was completed in May 2021 to assess current conditions of the monitoring wells and current groundwater quality to use in potential remedial decision making.
- The top of the sediments in Middle Creek was surveyed in May 2021 to address the EPA's concern that Evergreen's depiction of Middle Creek on cross section figures was not representative.
- Six wells were resurveyed in May 2021 to address the EPA's question about groundwater flow between AOI 7 and SWMU 9, since the EPA had questions concerning groundwater flow from SWMU 9 towards AOI 7.
- Two groundwater and surface water (Middle Creek) monitoring events (May 2021 and August 2021) were completed to collect groundwater elevations in AOI 7 in order to address the EPA's questions concerning groundwater flow direction, to address the EPA's request to conduct groundwater sampling during discharge to the river and to collect information to accurately design the IM. A combined AOI 7 and SWMU 9 monitoring event was completed on August 18, 2021 to collect synoptic readings in AOI 7 and SWMU 9 to better assess groundwater flow in the shallow and deep groundwater units.
- Six soil borings were completed in the northeastern portion of AOI 7, as shown on Figure 3, to address the EPA's questions concerning the potential for pyritic waste to be present in AOI 7 soils. An additional four borings were completed along the Delaware shoreline, as shown on Figure 3, to address the EPA's request to further characterize arsenic in this area. All borings were completed to a depth of 30 feet below ground surface (ft bgs). Soils were logged and continuous sampling was performed at each of these locations for soil classification. Arsenic and iron samples were collected with a frequency of every 5 feet for all borings with a bias towards the intervals where visual identification of materials resembling pyritic waste were observed, as requested by the EPA. The objective of this high-resolution characterization of arsenic in soils was to identify arsenic source areas in AOI 7. The EPA did not specifically request for iron soil samples, but Evergreen included iron in the sampling plan due to the fact that correlating the occurrence of arsenic and iron in soils would assist an assessment of potential arsenic mobility and the iron data were used along with other parameters in the arsenic mobility modeling, which was used to predict potential source areas in order to develop this IM Workplan.

- Five nested monitoring wells (shallow/deep pairs) along with seven deep wells (all of which are paired with existing shallow wells MW-560, MW-561, MW-562, MW-509, MW-558, MW-293, MW-56) were installed at the locations shown on Figure 3, at the request of the EPA. The objective of these wells was to identify arsenic source areas in both soil and groundwater. Shallow wells were advanced down to 15 ft bgs to be consistent with other shallow wells within AOI 7 and all deep wells were advanced down to 30 ft bgs to be consistent with existing deep well depths within AOI 7. Existing wells MW-536 and MW-537, identified as missing/inaccessible during the May 2021 investigation, were replaced as two of the nested well pairs. Wells (MW- 536RS/MW-536D, MW-537RS/MW-537D, MW-56D and MW-564S/D) were installed at boring locations (AOI7-BH-21-006, AOI7-BH-21-003, AOI7-BH-21-009, and AOI7-BH-21-008 respectively), as shown on Figure 3 and summarized on Table 5. Soils were continuously logged during the well installations and arsenic and iron samples were collected every five feet consistent with the procedures followed for the 10 completed borings previously described. In addition, one soil sample for GRO/DRO analysis was collected from each well location, at the request of the EPA, to further assess the potential for LNAPL to be a source of arsenic within AOI 7.
- Two groundwater sampling events were completed in May 2021 and August 2021. These events were completed to collect current data to assess arsenic in groundwater. Groundwater analyses included total and dissolved arsenic and iron for both groundwater sampling events. Field parameters (ORP, pH, DO, temperature, specific conductivity, turbidity) were included as a sampling parameter in order to build the site conceptual model and complete arsenic modeling. In addition, ten wells in August 2021 were sampled for sulfate, phosphate and arsenic speciation to inform the arsenic modeling and to inform the IM. The arsenic speciation (As(III or V), sulfate and phosphate were completed to evaluate arsenic mobility (either via biological or chemical mobilization) to assess mechanisms influencing arsenic mobility. Sulfate analyses were collected to identify potential arsenic correlation with pyritic minerals and as a constituent that can co-precipitate with arsenic as a potential in-situ treatment. Phosphate analyses were completed to inform competition of phosphate and arsenic to bind to iron oxides and hydroxides in the soil, potentially mobilizing arsenic from subsurface soils and informing in-situ treatment options such as permeable reactive barriers. The total arsenic and iron data along with the speciation data (As(III or V)) were collected to further support the arsenic mobility analysis for the site, and correlating these analyses with sulfate and phosphate data to inform where mobilization is occurring to inform the placement of the IM.
- LNAPL samples were collected and analyzed for arsenic and iron in July 2021 and August 2021 to address the EPA's concern that LNAPL is a source of arsenic to groundwater in AOI 7. LNAPL samples were collected from a well with low dissolved arsenic concentration in groundwater (MW-182), an existing well with high dissolved arsenic concentration in groundwater (MW-534L) and one of the newly installed wells that had high arsenic concentration in groundwater (MW-607D).

4.2 Soil Investigation

Section 4.1 presents the activities completed to characterize soil during the boring and well installations completed in 2021 in AOI 7.

4.2.1 Soil Boring and Monitoring Well Installation

Sanborn Head utilized existing utility maps and retained Ground Penetrating Radar Systems, Inc. (GPRS) to clear utilities using Ground Penetrating Radar and Radio Frequency Detection at each boring and monitoring location shown on Figure 3. Sanborn Head also worked with the drilling contractor (Parratt Wolff, Inc.) to support their completion of the PA One Call 811 as required by law three days prior to advancing the borings.

Following utility clearance, Sanborn Head oversaw the drilling contractor, Parratt Wolff, to install monitoring wells and borings. Ten soil borings were completed to 30 feet below grade as part of the field activities at the locations shown on Figure 3 and summarized on Table 5. The locations of these ten boring were chosen based on the request from the EPA to verify the presence of pyritic ore waste or to complete arsenic soil delineation at the Site. The locations of the borings selected to verify the pyritic ore was based on historic borings documented in the *1989 Ethylene Complex History of Landfilling Report*. Note that four locations (AOI7-BH-21-003, AOI7-BH-21-006, AOI7-BH-21-008, AOI7-BH-21-009) out of the ten total soil boring locations had a monitoring well installed after the boring was completed.

4.2.2 Soil Sampling

At the request of the EPA, soil samples were collected for arsenic and iron every 5 feet during completion of the borings and monitoring well installations. In addition, the EPA requested the collection of samples for GRO and DRO analysis to be collected at the frequency of one sample per well location. The established protocol for sample collection during the field activities included the following steps (note pyritic ore was not observed at any location):

1. Samples were collected every five feet for arsenic and iron analysis.
2. If there were no hydrocarbons or pyritic ore visually present, a sample was taken in the middle of the proposed well screen for arsenic/iron, GRO and DRO.
3. If pyritic ore was visually present and hydrocarbons were present, the arsenic/iron sample was taken where the pyritic ore was visually present and the GRO and DRO samples were collected where hydrocarbons were present; and
4. If pyritic ore was not visually present and hydrocarbons were visually present, arsenic/iron, GRO and DRO samples were collected where the hydrocarbons were present.

The samples were submitted to Eurofins Lancaster Laboratories for analysis of arsenic and iron via USEPA SW-846 method 6010 and SW-846 method 8015 for GRO/DRO consistent with methods used in the AOI 7 RFI. Data validation of the arsenic and iron soil samples collected is being completed by Environmental Standards. The data validation for the May 2021 sampling event is include in Appendix G. Due to the short time frame allowed by the EPA to complete the field activities prior to the submittal of this IM Workplan, there was not time to complete the data validation for the July and August 2021 activities to include in this submittal. The data validation will be submitted when available and any corrections

to table or figures from the IM Workplan will be made at that time. Laboratory reports are provided in Appendix G.

4.3 Groundwater Investigation

A total of 16 groundwater monitoring wells were installed in AOI 7 during the July 2021 field activities using hollow stem augers. The locations of the new monitoring wells are shown on Figure 3. Soil samples were collected during the monitoring well installations as is described in the previous section. Monitoring well installation logs are presented in Appendix D and Delaware well installation permits are also included in Appendix D.

4.3.1 Monitoring Well Installation

Five nested monitoring wells (shallow/deep pairs) along with six deep wells (all of which are paired with existing shallow wells MW-56, MW-293, MW-509, MW-558, MW-561, MW-562) were installed at the locations shown on Figure 3. Note that existing well MW-560 was originally planned to have a paired deep well installed, however, the eroding shoreline of Middle Creek did not provide sufficient nor safe access for monitoring well installation. Shallow wells were advanced down to 15 ft bgs and all deep wells were advanced down to 30 ft bgs to be consistent with existing shallow and deep well depths within AOI 7. The screen intervals were generally set at 5 to 15 ft. bgs to investigate water table conditions (for shallow wells with “S” designation) and at 20 to 30 ft. bgs (deeper wells with “D” designation) to investigate deeper conditions with an adequate vertical separation from the shallower screened wells. The two exceptions include MW-606S and MW-606D that were installed down to 20 ft bgs (with a well screen from 10 to 20 ft bgs) and 35 ft bgs (with well screen from 25 to 35 ft bgs) due to the elevation differences relative to the other monitoring well locations.

Existing monitoring wells MW-536 and MW-537 that were identified as missing/inaccessible during the May 2021 investigation were replaced as two of the nested well pairs (MW-536RS/MW-536RD and MW-537RS/MW-537RD). Monitoring wells MW-536RS/MW-536RD, MW-537RS/MW-537RD, MW-56D, MW-607S/MW-607D were installed at soil boring locations AOI7-BH-21-006, AOI7-BH-21-003, AOI7-BH-21-009, and AOI7-BH-21-008 respectively, as shown on Figure 3 and summarized on Table 5. Well construction information for the newly installed wells is provided in Table 6.

4.3.2 Groundwater Monitoring Well Gauging

Sanborn Head performed a groundwater gauging event in all existing and accessible monitoring wells located in AOI 7 in May 2021 and another event with all existing and accessible monitoring wells in AOI 7 and SWMU 9 in August 2021. The groundwater elevations collected during the August 2021 groundwater gauging event were collected during mid to low tide (falling tide) to reflect discharge towards the Delaware River to respond to the EPA’s June 23, 2021 request. Groundwater gauging completed during the May 2021 gauging event was completed during mid to high tide, since this event occurred prior to receiving the EPA’s June 23, 2021 request. During these gauging events, the condition of wells was inspected and the depth to groundwater from a surveyed reference point was obtained as well as the depth to LNAPL (if present). The shallow and deep

groundwater contours from the August 2021 gauging event are summarized on Figures 11 and 12. The results from the groundwater gauging are summarized on Table 2.

4.3.3 May 2021 Groundwater Sampling Event

Prior to the new well installations that occurred in July 2021, Sanborn Head sampled the existing 32 monitoring wells within AOI 7 for total arsenic and iron and dissolved arsenic and iron to assess arsenic concentrations in groundwater. Of these monitoring wells, three had become inaccessible since the latest RFI sampling round in 2016. MW-536 and MW-539 were unable to be located due to previous demolition activities and MW-537 was backfilled with sand.

Prior to sample collection, static water levels were measured at all monitoring wells to inform groundwater flow in the shallow and deep groundwater zones, as well as determining the occurrence of LNAPL in these monitoring wells. A depth-to-bottom measurement was also collected post-sampling to identify any changes in the well conditions since the last sampling round (no changes were noted). A groundwater sample was collected even if LNAPL was detected in the monitoring well, following specialized procedures to ensure LNAPL was not present in the groundwater sample, but the groundwater elevations are modified based on the measured thickness of the detected LNAPL.

Two sampling methods were used to collect groundwater samples from the wells at AOI 7. Wells that did not have LNAPL present were sampled using USEPA low-flow sampling methods which included the collection of stabilized geochemical parameters including pH, specific conductivity, oxidation-reduction potential (ORP), and dissolved oxygen (DO) through the use of a water quality meter. Samples that had LNAPL present were sampled using the following procedure:

- A larger inner diameter tubing was capped at the bottom and placed in the well at the middle of the screen. Tubing was left in the well for 24 hours to reach stabilization with LNAPL present in the water column.
- After 24 hours, a smaller inner diameter tubing was deployed through the larger diameter tubing and pierced through the cap at the bottom of the larger tubing.
- Using a peristaltic pump, groundwater was purged from the well for approximately 5 minutes and then sampled. Drawdown was monitored to be cautious of the LNAPL-water interface.

For both sampling methods, dissolved samples were collected through 45 micron in-line field filters following well stabilization. All samples were submitted to Eurofins Laboratories for analysis of total arsenic and iron and dissolved arsenic and iron via USEPA SW-846 method 6010 or 6020.

4.3.4 August 2021 Groundwater Sampling Event

Evergreen had proposed a synchronous gauging and sampling event in AOI 7 and SWMU 9 in their April 13, 2021 correspondence, and gauging/sampling SWMU 9 wells was included

in the EPA's June 23, 2021 correspondence. Evergreen was not granted access to SWMU 9 wells until August 13, 2021, which was after the groundwater sampling event which occurred August 10, 2021 to August 12, 2021. Evergreen re-mobilized after receiving access to SWMU 9 to complete gauging in AOI 7 and SWMU 9, but samples were not collected since results would not have been available to be evaluated until after the IM Workplan was due to the EPA .

After a one-to-two-week stabilization period, the newly installed monitoring wells in AOI 7 were sampled. Prior to sample collection, the occurrence of LNAPL in these monitoring wells were determined using an oil-water interface probe. LNAPL was found at the following new wells: MW-56D, MW-564S, MW-564D. A groundwater sample was collected from the newly installed monitoring wells even if LNAPL was detected in the monitoring well following the procedures used for the May 2021 sampling event.

Groundwater samples were collected from all new monitoring wells in AOI 7 (16 monitoring wells in total) following the same procedures as the May 2021 sampling event. Groundwater elevations from all existing AOI 7 and select SWMU 9 wells were collected on August 18, 2021 during mid to low tide (falling tide) to reflect discharge towards the Delaware River to respond to the EPA's June 23, 2021 request. Due to site logistics, including access to certain wells due to the train schedule, presence of LNAPL in some wells resulting in sample collection 24 hours after inserting tubing and the overall number of wells to be sampled, not all of the samples were able to be collected during mid to low tide during the August 2021 event.

All of the newly installed wells were sampled for total and dissolved arsenic and iron. The dissolved samples were field filtered with 45 micron in-line field filters following well stabilization. Ten of the AOI 7 monitoring wells were also sampled for sulfate, phosphate and arsenic speciation. These additional analyses were completed to inform potential source areas of arsenic and the interim remedy options by evaluating arsenic mobility (either via biological or chemical mobilization). Specifically, sulfate analyses aided in the identification of arsenic correlated with pyritic minerals (used for sulfuric acid production) and as a constituent that can co-precipitate with arsenic. Phosphate analyses helped to inform competition of phosphate and arsenic to bind to iron oxides and hydroxides in the soil, potentially mobilizing arsenic from subsurface soils and informing remedy options.

All samples were submitted to Eurofins Laboratories for analysis of arsenic and iron via USEPA SW-846 method 6010, sulfate via USEPA Method 300, phosphate via USEPA Method 365.1 and arsenic speciation via USEPA Method 1632. Data validation was conducted for the total and dissolved arsenic/iron groundwater samples collected during this event and are being completed by Environmental Standards. Laboratory and data validation reports will be provided when available.

4.3.5 LNAPL Sampling

Sanborn Head also collected three LNAPL samples to address the EPA's concern that LNAPL was a source of arsenic to groundwater. The samples were collected as follows: 1) one sample from a well with low groundwater arsenic concentrations (MW-182); 2) one

sample from an existing well with high groundwater arsenic concentrations (MW-534L); and 3) one sample from a newly installed monitoring well that contained LNAPL and was located in an area of predicted high arsenic concentration in groundwater (MW-607D) . The arsenic samples were collected using bailers. All samples were submitted to Eurofins Test America Laboratories of Valley Forge, Pennsylvania for analysis of arsenic and iron via USEPA SW-846 method 6010.

5.0 2021 INVESTIGATION RESULTS

Section 5.0 presents the results of the 2021 investigation activities that were completed at the request of the EPA in relation to the IM remedy for AOI 7. Table 2 summarizes the groundwater elevations from the May and August sampling events. Table 2 also notes when on the tide cycle the groundwater elevations and groundwater samples were collected. Table 5 summarized all of the activities that were completed as part of the 2021 investigation activities. Tables 7 and 8 present the analytical soil data collected as part of the 2021 AOI 7 field activities. Tables 9 through 11 present groundwater/LNAPL analytical results. Table 11 presents the groundwater geochemistry from the field parameters. Figure 3 shows all of the completed sample locations and Figures 14 through 27 show the results of the 2021 AOI 7 field activities. Appendix G includes laboratory reports for analyses on the soil and groundwater results collected in 2021. Appendix G presents the validation report on the May 2021 groundwater analyses.

5.1 Soil

5.1.1 Arsenic

A total of 118 soil samples for arsenic analyses were collected during the 2021 investigation activities. The results of the arsenic soil data are summarized on Table 7. Figure 14 presents the distribution of arsenic in soil data from the July 2021 event and Figure 15 presents the distribution of arsenic in soil and sediment including historic data from May 2003 to present data in July 2021. For borings that had samples taken at varying depths, the maximum arsenic concentration is presented on both Figure 14 and Figure 15. The highest arsenic concentrations within AOI 7 are located in the southwestern area of AOI 7, in the historically filled area that was impacted by materials migrating from SWMU 9, as shown in the historical aerials in Appendix B. Arsenic concentrations ranged from non-detect to 11,000 mg/kg on AOI 7. The highest arsenic in soil concentrations at AOI 7 were found at depths between 24 and 30 ft bgs in a very limited portion of AOI 7 (southwest corner). No potential source areas for arsenic in soil were identified based on the completed sampling, with the exception of the previously identified southwestern portion of AOI 7, which was due to historic deposition from SWMU 9. Further supporting this conclusion is that the highest arsenic soil concentration was still found to be located in SWMU 9 at MW-124S with a concentration of 14,100 mg/kg at 14 to 16 ft bgs, as shown on Figure 15.

5.1.2 Iron

A total of 118 soil samples for iron analyses were collected during the 2021 investigation activities. The results of the iron soil data are summarized on Table 7. Figure 16 presents the distribution of iron in soil data from the July 2021 event and Figure 17 presents the

historical distribution of iron in soil and sediment. For borings that had samples taken at varying depths, the maximum iron concentration is presented on both Figure 16 and Figure 17. Iron concentrations in soil ranged from non-detect mg/kg to 628,000 mg/kg across AOI 7 and SWMU 9. The highest iron concentrations in soil were found in the northern portion of AOI 7 at depths of 5 to 15 ft bgs. As is further discussed in Section 6.0, an inverse relationship was observed in the areas of high arsenic concentrations in groundwater and iron concentrations in soil, which supported Evergreen's conclusions in their December 14, 2021 correspondence that arsenic mobility within SWMU 9 and AOI 7 was potentially related to the desorption of arsenic from the iron oxide surfaces to which it was previously bound, when mediated by changes in groundwater chemistry.

5.1.3 DRO and GRO

A total of 16 samples were collected for DRO and GRO during the 2021 investigation activities. Table 8 presents the analytical results for DRO and GRO. DRO values ranged from 27 to 66,000 mg/kg. The highest DRO concentration was found at MW-558D in the 15 to 20 ft bgs interval. This location was noted to have product in the boring logs at this interval. GRO values ranged from 3 to 870 mg/kg, with the highest GRO concentration located at MW-607D in the 10 to 15 ft bgs interval. Overall, concentrations of DRO were higher than GRO in the 16 sample locations. There was no observed correlation between the occurrence of DRO and GRO and arsenic in soil, as shown by the figures in Appendix H, supported Evergreen's conclusions in their December 14, 2021 correspondence that the LNAPL in AOI 7 is not a source of arsenic to groundwater in AOI 7.

5.2 Groundwater

5.2.1 Shallow Groundwater Elevations

Groundwater elevations were collected in May and August 2021 and are summarized on Table 2. A comprehensive round of groundwater level measurements were collected during the sampling event in August 2021. The calculated elevations are presented on Figures 11 and 12 for the AOI 7 and SWMU 9 groundwater elevations in 2021 for both shallow and deep groundwater. Groundwater elevations in the shallow groundwater unit in both AOI 7 and SWMU 9 are approximately 1 to 2.5 feet AMSL, adjacent to Middle Creek and along the Delaware River. As seen in Figure 11, mounding is observed in shallow groundwater elevations from approximately 4 to 8 ft AMSL coincident with historic filling. Also seen in Figure 11, groundwater flows radially from this high in the center of AOI 7, towards the Delaware River and Middle Creek. The contours also indicate preferential groundwater pathways in AOI 7 correlating with the 1951 location of Middle Creek. Other localized mounding is also observed in selected AOI 7 wells based on water seepage from nearby fire water lines, but wells with these mounding effects are not included in the shallow contours on Figure 11. Shallow groundwater flow in SWMU 9 towards the Delaware River and Middle Creek, as shown on Figure 11.

5.2.2 Deep Groundwater Elevations

Groundwater elevations in the deep groundwater unit are approximately 1 to 2.5 feet AMSL adjacent to Middle Creek and 2 to 3 ft AMSL along the Delaware River. As seen in Figure 12, mounding is also observed in deep groundwater elevations from approximately

4 to 7 ft AMSL in the center of AOI 7 coincident with historic filling. Also seen in Figure 12, deep groundwater flows towards the Delaware River and Middle Creek. The contours also indicate slight preferential groundwater pathways correlating with the 1951 location of Middle Creek. Other localized mounding is also observed at one location based on water seepage from nearby fire water lines which are not included on the contours in Figure 12. Deep groundwater flow in SWMU 9 flows is towards the Delaware River with localized flow along the eastern border towards AOI 7, as shown on Figure 12.

The groundwater elevations and contours confirmed that there is complicated flow in the deep groundwater and there is a component of flow in the deeper unit from SWMU 9 towards AOI 7, which had been previously concluded by Evergreen (Appendix C) and DVW (Appendix E).

5.2.3 Vertical Gradients

Vertical gradients were calculated from the August 18, 2021 groundwater elevations by dividing the difference of the shallow and deep groundwater elevations at a well pair locations by the vertical distance between the mid-points of the wells screens. A negative gradient indicates a downward gradient while positive gradients indicate an upward gradient. The calculated vertical gradients are summarized on Table 3. The vertical hydraulic gradients between shallow groundwater and deep groundwater ranged from -0.000702 to 0.256 ft/ft for wells along the Delaware River. For wells towards Middle Creek, the vertical hydraulic gradients ranged from -0.0143 to -0.329 ft/ft. These vertical gradients, shown on Figure 10, support that groundwater is discharging upwards along the Delaware River in the eastern portion of AOI 7. Groundwater along the western boundary with the Delaware River and the remainder of AOI 7 is downward, resulting in the potential for conditions in the shallow groundwater unit in these areas to influence groundwater quality in the lower groundwater unit.

5.2.4 Groundwater and Surface Water Elevations

As shown on Figure 11 and 12, the surface water elevation in Middle Creek is 3.5 ft AMSL, which is approximately 2 feet higher than the adjacent groundwater elevations. Evergreen surveyed the elevation of Middle Creek bed surface in May 2021 as is summarized on Table 4 and shown on Figures 7 and 8. The elevation of Middle Creek bed is generally within the screened interval of the shallow wells and above the screened interval of the deep wells. While overall groundwater flow in the vicinity of Middle Creek is expected to be toward Middle Creek, due to the tidal nature of Middle Creek and the fact that it is a man-made feature, the interaction between surface water and groundwater is expected to be variable in the vicinity of Middle Creek, especially at the mouth of the Delaware River. As shown in Figure 12, there is component of flow in the deeper groundwater that is expected to go beneath Middle Creek.

5.2.5 Groundwater Analytical Results

A total of 54 monitoring wells were sampled during the 2021 field activities, including 37 in May 2021 during the sampling event of existing wells and the remaining 17 newly installed wells in August 2021. A total of 62 groundwater samples and 3 LNAPL samples were collected from AOI 7 locations during the 2021 field activities.

5.2.5.1 Arsenic in Groundwater

Table 9 presents the results of the total and dissolved arsenic in groundwater. Total arsenic in groundwater concentrations and dissolved arsenic in groundwater concentrations ranged from non-detect to 1,500 mg/L. The highest total and dissolved arsenic concentration was found at MW-532L, which is consistent with the RFI analytical results. Figure 18 compares total arsenic versus dissolved arsenic concentrations in groundwater. As shown in Figure 18, the total arsenic concentrations correlate with dissolved arsenic concentrations supporting that the dissolved arsenic concentrations are representative of Site conditions, therefore all groundwater figures in this IM Workplan depicting arsenic data used the dissolved arsenic data. Figure 19 shows the dissolved arsenic results of the 2021 groundwater sampling in the shallow and deep groundwater units. Figure 20 shows the historic distribution of dissolved arsenic in groundwater and porewater across AOI 7 and SWMU 9. When there were multiple events for the same well, the latest data are shown as summarized on Figure 20.

- As shown in Figure 19, shallow AOI 7 groundwater arsenic concentrations range from non-detect to 35 mg/L. Four out of the total 32 shallow wells had concentrations above the arsenic groundwater PRG developed by Honeywell for the DVW site for the protection of porewater. The highest dissolved arsenic concentrations in shallow groundwater in AOI 7 are located in the southwestern corner of AOI 7 spanning from MW-606S to MW-607S. This finding is consistent with the findings of the AOI 7 RFI, with the impacted area slightly larger than previously identified due to the installation of additional wells.
- As shown in Figure 19, deep AOI 7 groundwater arsenic concentrations range from non-detect to 1,500 mg/L. Seven out of the total 19 deep wells had concentrations above the arsenic groundwater PRG developed by Honeywell for the DVW site for the protection of porewater. The highest dissolved arsenic concentrations in deep groundwater in AOI 7 are located in deep groundwater in the southwestern corner of AOI 7 spanning from MW-606D to MW-534L. This finding is consistent with the findings of the AOI 7 RFI, with the impacted area slightly larger than previously identified
- As shown in Figure 20, shallow SWMU 9 groundwater arsenic concentrations range from non-detect to 41.8 mg/L. Three out of the total eight shallow wells had concentrations above the arsenic groundwater PRG developed by Honeywell for the DVW site for the protection of porewater. The highest dissolved arsenic concentrations in groundwater are located in the western portion of SWMU 9.
- Deep SWMU 9 groundwater arsenic concentrations range from non-detect to 0.409 mg/L. Zero out of the six deep wells had concentration above the arsenic groundwater PRG developed by Honeywell for the DVW site for the protection of porewater. It should be noted that the deep wells in SWMU 9, especially those installed along Middle Creek were installed with the objective to screen the sand and gravel (Stratum 4) as identified on the DVW Site. As shown on Figure 7, the deep wells on SWMU 9 are screened at an elevation lower than the deep wells on AOI 7. In addition, the AOI 7 deep wells are screened in the silty clay unit, rather than the sand and gravel. The silty clay unit is more representative of the materials that would have been deposited by materials migrating

from SWMU 9 before AOI 7 was filled to make land, so direct comparison of the deep groundwater from MW-123D and MW-124D and the deep wells on AOI 7 is not representative of the same conditions.

5.2.5.2 Iron in Groundwater

Table 9 presents the results of the total and dissolved iron data in groundwater. Total iron in groundwater concentrations ranged from non-detect to 490 mg/L and dissolved iron in groundwater concentrations ranged from non-detect to 450 mg/L. The highest total and dissolved iron in groundwater concentration was found at MW-558D and MW-557, respectively. Figure 21 compares total iron versus dissolved iron concentrations in groundwater. As shown in Figure 21, the total iron concentrations correlate with dissolved iron concentrations supporting that the dissolved iron concentrations are representative of Site conditions, therefore all groundwater figures in this IM Workplan depicting iron data used the dissolved iron data. Figure 22 shows the dissolved iron results of the 2021 groundwater sampling in the shallow and deep groundwater units. In general, high dissolved iron concentrations are similar in distribution to dissolved arsenic concentrations, supporting the conclusions included in Evergreen's December 14, 2021 correspondence that arsenic mobility within SWMU 9 and AOI 7 was potentially related to the desorption of arsenic from the iron oxide surfaces to which it was previously bound, when mediated by changes in groundwater chemistry.

- As shown in Figure 22, shallow AOI 7 groundwater iron concentrations range from non-detect to 450 mg/L. These iron data are correlated with observed high arsenic concentrations in groundwater, as supported by the figures in Appendix H.
- As shown in Figure 22, deep AOI 7 groundwater iron concentrations range from non-detect to 390 mg/L. These iron data are correlated with observed high arsenic concentrations in groundwater, as supported by the figures in Appendix H.

5.2.5.3 Sulfate and Phosphate in Groundwater

Table 10 displays the analytical results for sulfate and phosphate in groundwater sampled at 10 of the new monitoring well locations (MW-56D, MW-293D, MW-509D, MW-537RS, MW-537RD, MW-561D, MW-606S, MW-606D, MW-607S, MW-607D), with the collection of 3 samples in shallow wells and 7 samples in deep wells. The following summarizes the results in more detail.

Sulfate - Overall, sulfate concentrations ranged from 41 to 9,000 mg/L, with the highest sulfate concentration located at MW-606D (towards the corner of Middle Creek and the Delaware River). Sulfate concentrations in the shallow groundwater ranged 620 to 2,400 mg/L, with the highest at MW-606S. Sulfate concentrations in the deep groundwater ranged 41 to 9,000 mg/L, with the highest at MW-606D. Overall, the sulfate data is highest along Middle Creek.

Phosphate - Overall, phosphate concentrations ranged from 0.35 to 95 mg/L, with the highest phosphate concentration also located at MW-606D. Phosphate concentrations in the shallow groundwater ranged 0.35 to 34 mg/L, with the highest at MW-606S. Phosphate

concentrations in the deep groundwater ranged 0.52 to 95 mg/L, with the highest at MW-606D. Phosphate concentrations were highest in the southwestern corner of AOI 7.

Sulfate and phosphate concentrations seemed to be higher in deeper wells as compared to their shallow well pair. These analyses were completed to inform the remedial alternative and will be discussed further in the Site Conceptual Model section below. Additional water quality data (i.e., pH, ORP, DO, temperature, turbidity, and specific conductance) is provided in Table 11.

5.2.5.4 ORP in Groundwater

62 field measurements for ORP were made during the groundwater sampling events, as summarized on Table 11. The ORP data from the 2021 field event is included on Figure 23. Overall, ORP concentrations ranged from -263 to 445 mV. ORP in the shallow groundwater ranged -263 to 445 MV, with the lowest at MW-531U. ORP in the deep groundwater ranged -236 to 256 mV, with the lowest at MW-532L. The overall pattern of the ORP data shows correlation of lower ORP (reduced conditions) in areas where LNAPL is observed, as can be expected due to enhanced biodegradation in these areas. These results were consistent with what was observed in the RFI and Evergreen's December 14, 2021 correspondence.

5.2.5.5 pH in Groundwater

62 field measurements for pH were made during the groundwater sampling events, as summarized on Table 11. The pH data from the 2021 field event is included on Figure 24. Overall, pH concentrations ranged from 3.36 to 7.50. pH in the shallow groundwater ranged 3.36 to 7.50, with the lowest at MW-560. pH in the deep groundwater ranged 5.09 to 7.45, with the lowest at MW-122 on SWMU 9. The overall pattern of the pH data were consistent with what was observed in the RFI and Evergreen's December 14, 2021 correspondence., indicating an area of low pH in shallow groundwater at SWMU 9 immediately upgradient of AOI 7.

5.2.5.6 DO in Groundwater

62 field measurements for DO were made during the groundwater sampling events, as summarized on Table 11. The DO data from the 2021 field event (from two events in August 2021 to complete confirmatory sampling of DO due to a potential faulty sensor) is included on Figure 25. Overall, DO ranged from 0.10 to 7.30 mg/L. DO in the shallow groundwater ranged 0.10 to 6.14 mg/L, with the lowest at MW-57. DO in the deep groundwater ranged 0.19 to 7.30 mg/L, with the lowest at MW-530L. The overall pattern of the DO data shows correlation of lower DO (anoxic conditions) in areas where LNAPL is observed, as can be expected due to enhanced biodegradation in these areas. Also note that there were overall high DO concentrations on SWMU 9 which would aid in immobilizing arsenic. These results were consistent with what was observed in the RFI and Evergreen's December 14, 2021 correspondence.

5.2.5.7 Temperature in Groundwater

62 field measurements for temperature were made during the groundwater sampling events, as summarized on Table 11. The temperature data from the 2021 field event is

included on Figure 26. Overall, temperature from 13.43 to 26.69°C. Temperature in the shallow groundwater ranged 13.43 to 26.69°C, with the lowest at MW-527U. Temperature in the deep groundwater ranged 13.48 to 23.83°C, with the lowest at MW-530L. The overall pattern of the temperature data shows indications of potential surface water influences and/or firewater line leakage.

5.2.5.8 Specific Conductivity in Groundwater

62 field measurements for specific conductivity (SC) were made during the groundwater sampling events, as summarized on Table 11. The SC data from the 2021 field event is included on Figure 27. Overall, SC ranged from 218 to 15,500 uS/cm. SC in the shallow groundwater ranged 218 to 15,500 uS/cm, with the lowest at MW-540. SC in the deep groundwater ranged 726 to 15,400 uS/cm, with the lowest at MW-530L. Similar to temperature, the overall pattern of the SC data shows indications of potential surface water influences and/or firewater line leakage. In addition, the SC data reflects the cation/anions available in the groundwater which is also useful for IM design.

5.2.5.9 Arsenic Speciation

The arsenic speciation was completed to assist in the identification of the mobile fraction of the arsenic in groundwater. Due to the timeframe required by the EPA to submit the IM Workplan, the laboratory was not able to complete the arsenic speciation analysis before the submittal of this report. These data will be submitted when they are available.

5.3 LNAPL Analysis

Three LNAPL samples were collected from MW-182, MW-534L and MW-607D for arsenic and iron analyses. Results of arsenic and iron concentrations in these three LNAPL samples are shown in Table 12. The arsenic results are also shown on Figure 14. Concentrations of arsenic in LNAPL ranged from 8.9 to 330 mg/kg, and concentrations of iron in LNAPL ranged from 39 to 640 mg/kg. Arsenic in LNAPL did not show a correlation to arsenic in groundwater supports that arsenic in LNAPL is not a source to arsenic in groundwater, as will be further discussed in Section 6.

5.4 Summary

As stated in Section 1.1 three questions were identified by Evergreen to be addressed to be able to respond to the EPA's request for an IM for arsenic in groundwater in AOI 7. These questions included: 1) what is the source material for the observed arsenic concentrations, 2) what conditions exist that are resulting in the mobilization of the arsenic; and 3) what is the appropriate remedial action objective for the IM?

The following summarizes the findings of the 2021 investigation activities in relation to the first question relating to source area.

- No pyritic waste was noted in the borings and no elevated arsenic soil data was noted at the depth intervals where the pyritic waste was noted in historic logs. Pyritic waste is not a source of the dissolved arsenic in groundwater in AOI 7.

- Elevated soil concentrations of arsenic were not correlated with DRO or GRO. Nor were elevated arsenic concentrations detected in the LNAPL samples. LNAPL is not a source of arsenic to groundwater in AOI 7.
- The southwestern portion of AOI 7 was confirmed by both soil and groundwater data to be the area with elevated arsenic concentrations in soil and groundwater. These results are delineated by the completed activities. No other source areas for arsenic were identified within AOI 7.

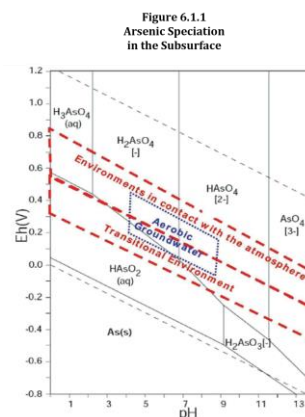
The following sections utilize the additional data collected during the 2021 activities to evaluate what conditions could mobilize arsenic. A discussion regarding the path forward to address the appropriate remedial endpoint is also include in relation the IM.

6.0 FATE AND TRANSPORT EVALAUTION

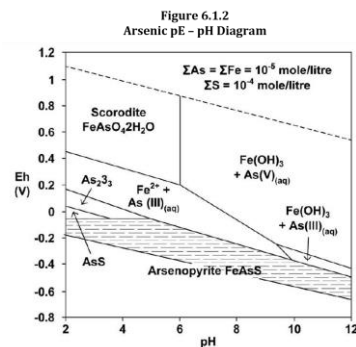
Due to the fact that the location of the highest detections of arsenic in soil do not correlate with the highest detections in groundwater, additional evaluation was completed to assess the potential factors that may exist within SWMU 9 or AOI 7, which would cause arsenic to be mobilized and occur at elevated concentrations in groundwater. Evergreen completed initial soil to groundwater calculations in the December 14, 2020 correspondence to evaluate factors controlling arsenic mobilization. As part of this IM Workplan, arsenic concentrations in soil and groundwater were modeled to determine the geochemistry necessary to create mobilization of arsenic in groundwater using soil-to-groundwater calculations, PHREEQC modeling and PCA analysis. This advanced modeling was completed to further evaluate arsenic mobility since the 2021 activities confirmed that the highest arsenic concentrations in soil still did not correlate with groundwater, although some higher arsenic detections were noted during the 2021 investigations within AOI 7. The groundwater geochemistry that is affecting arsenic mobilization is important to understand in relation to designing an appropriate IM.

6.1 Arsenic Fate and Transport

The fate and transport of arsenic in groundwater is dominated by the fact that arsenic is redox-labile, readily changing its oxidation state or chemical form through chemical or biological reactions that are common in the environment. Therefore, rather than solubility equilibria controlling the aqueous behavior of arsenic, it is controlled primarily by redox conditions and pH as shown by Figure 6.1.1. These two factors control, mineral formation/dissolution, and adsorption/desorption reactions.



The common valence states of arsenic are As0, As-3, As+3, and As+5. The last two of these (As+3, and As+5) are the most commonly encountered valence states in groundwater as the oxyanions AsO₃-3 (arsenite) and AsO₄-3 (arsenate). Arsenite is generally more soluble than arsenate. These two species can vary in relative concentration in groundwater depending on the redox state of the groundwater. Typically, in aerobic aquifers, As+5 dominates; in anoxic or reduced aquifers, As+3 is dominant (Brown et al, 2011).



The mineralogy of arsenic suggests that there are two redox environments that form stable arsenic minerals. Arsenates (As+5) exist in oxidized or aerobic environments. Sulfidic minerals, such as arsenopyrite (FeAsS), or realgar (As₄S₄ or AsS), are formed in strongly reducing, anoxic environments where sulfate reduction occurs. The speciation of arsenic in these environments under different redox and pH conditions, and in the presence of iron, are shown to the right in Figure 6.1.2. Typically, groundwater redox values are determined by the Eh from the relative concentrations of a specific redox couple such as the iron III – iron II couple. Thus, arsenic speciation will be controlled by the dominant redox couple and the Eh of that couple in the aqueous phase (Brown, et al, 2011). The ratio of arsenite to arsenate in anoxic and reduced aquifers is a function of the Eh.

The pH of the groundwater is the second most important factor controlling the ambient solubility of arsenic. The pH has two primary effects. First, it affects the ionic form of the arsenic. High pH increases the solubility of arsenic species. pH also affects the sorption of arsenic oxyanions. At very low (acidic) pH, the metal sorption site is attacked, often dissolving the metal and releasing any sorbed arsenic. At high pH, the sorption of the oxyanions will also decrease as they are displaced by hydroxide ions (Sutherson and Horst, 2008). The optimal pH range for sorption is 4 to 8, or in other words arsenic mobility will increase below pH 4 and above pH 8. The primary forms of inorganic arsenic in both oxidizing and reducing groundwater are oxyanions or thioanions (Ferguson and Gavis, 1972; Wilkin et al., 2003; Bostick et al., 2005). Adsorption of these arsenic species at mineral surfaces occurs as a result of a set of chemical reactions between aqueous species and surface sites (Dzombak and Morel 1990; Davis and Kent, 1990). The most important reactive surface phases for arsenic attenuation in many soil and subsurface systems are cationic metal surfaces, including iron, aluminum, and calcium mineral phases. Arsenic sorption has been demonstrated for a wide range of minerals common to soils and sediments with iron oxides and sulfides playing a dominant role in oxidizing and reducing environments (Goldberg and Glaubig, 1988; de Vitre et al., 1991; Morse, 1994; McNeill and Edwards, 1997; Manning et al., 1998; Chiu and Hering, 2000; Wolthers et al., 2005).

Adsorption of both As+3 and As+5 onto mineral surfaces exhibits a strong pH dependence, with a pH range of 4 to 8 being optimal, because:

1. Most adsorption reactions between As+3 and As+5 and mineral surface sites have H⁺ as a reactant;
2. Arsenic speciation varies with pH; and

3. The electrostatic contribution to the free energy of adsorption of arsenic species onto most minerals varies with pH.

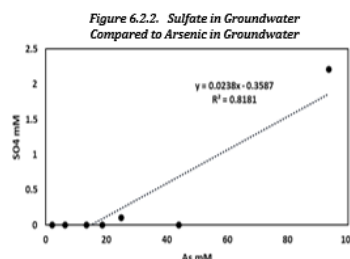
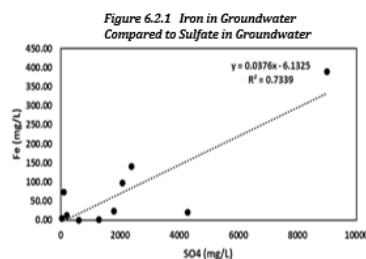
The extent to which As+3 or As+5 anions adsorb at mineral surfaces will also be influenced by the concentrations of other anions, which can compete for surface sites, and cations, which can influence the electrostatic contribution to anion adsorption.

6.2 Modeled Arsenic in Groundwater

The PHREEQC modeling completed for AOI 7 used geochemical parameters (field parameters, sulfate and phosphate) to analyze the speciation of arsenic in groundwater in order to predict arsenic mobility. PHREEQC is a computer program designed to model groundwater geochemistry in the subsurface through ion-association aqueous modeling. Specifically, the program calculates speciation and saturation-index, reaction-path and advective-transport mechanisms, mixing of solutions, mineral and gas phases, surface-complexation reactions, and ion-exchange reactions. PHREEQC was used to model the arsenic and geochemistry in groundwater, and the results of the model are provided in Appendix I. Note that geochemistry inputs included (but were not limited to) pH, ORP, DO, iron sulfate and phosphate data that was collected during the August 2021 field event.

Arsenic mobility can be mitigated by the presence of mineral precipitates on the soil grains, particularly iron oxyhydroxides. Both arsenate and arsenite can be adsorbed by these materials, thus reducing their mobility. The Saturation Index (SI) output in PHREEQC revealed a positive SI value mostly for iron oxides (goethite, hematite, magnetite) as well as the phosphate mineral vivianite. These results suggest that elevated arsenic concentrations are controlled by the dissolution of Fe minerals and the dissolution of phosphate minerals. The process of dissolution is dependent on several factors such as pH, Eh, among others (e.g., organic matter and presence of other oxyanions). The PHREEQC modeling study revealed that sulfate is likely in the dissolved phase and it is not saturated in the aqueous environment. Phosphate is saturated in most of the wells that had a pH below 7 and is precipitated as vivianite then removed from groundwater. Overall, phosphate concentrations are higher at in deep groundwater, which is consistent with historic fill containing phosphate-laden materials (from pesticide production, etc.) and historic deposition from SWMU 9.

The wells with the highest arsenic concentrations that are located near the Delaware River also have high iron concentration and medium to high sulfate and phosphate concentrations: MW-606D, MW-607D and MW-56D. Figures 6.2.1 and 6.2.2 below show the correlation between iron/arsenic and sulfate.



The relatively high presence of iron, arsenic and sulfate, along with the high correlation (0.73) between iron and sulfate as well as arsenic and sulfate (0.81) indicates a possible source is biogenic in origin and partly geochemical. This conclusion is consistent with the redox conditions observed in the subsurface.

Under oxidizing conditions, As(V) can hydrolyze to four possible species depending on the range of pH encountered in surface and groundwater systems. In oxygenated water systems, arsenious acid (H_3AsO_4) is predominant only at extremely low pH values (<2), whereas a pH range of 2 to 11 shows arsenic in the form of H_2AsO_4^- and HAsO_4^{2-} . In reducing environments and at low pH, arsenious acid can convert into H_2AsO_3^- . In the pH range of 4 to 10, As(V) species is negatively charged in water, whereas the predominant As(III) species is neutral in charge because of redox potential and the presence of complexing ions such as sulfur, iron, and calcium and microbial activity.

Soil-to-groundwater calculations were partnered with PHREEQC and geochemical parameters to estimate the arsenic in groundwater concentrations due to leaching of arsenic from soils and encountering varying groundwater geochemistry. The geochemistry and soil concentrations were used to predict the arsenic in groundwater concentration in ten locations. These calculations and results are provided in Appendix I as well as in Table 6.2.1 below using the geochemistry parameters taken at each well.

Table 6.2.1. Modeled Arsenic in Groundwater Concentrations

Location	As Soil Conc. (mg/kg)	pH (s.u.)	ORP (mV)	DO (mg/L)	Phosphate (mg/L)	Sulfate (mg/L)	As GW Conc (mg/L)	Modeled As GW Conc (mg/L)
MW-56D	4,500	6.11	-126	0.75	78	41	170	85.8
MW-293D	6.1	6.12	-8	1.43	0.72	210	0.28	0.449
MW-509D	850	6.43	-116	1.3	16	4,300	0.078	19.5
MW-537RS	100	7.5	5	0.63	0.35	620	0.027	2.00
MW-537RD	4.3	7.31	14	3.41	0.52	1,300	0.023	0.187
MW-561D	49	6.55	-29	0.63	1.6	1,800	0.61	1.93
MW-606S	780	6.47	-124	1.01	34	2,400	35	17.8
MW-606D	6,400	6.42	-145	0.9	95	9,000	730	94.4
MW-607S	100	6.51	-102	0.42	29	2,100	24	3.47
MW-607D	3400	6.34	-98	0.22	67	110	100	60.5

Overall, most modeled concentrations were within the order of magnitude of the analytical results for dissolved arsenic in groundwater, with the exception of MW-509D, MW-537RS and MW-606D. These exceptions are discussed further below:

- The modeling overpredicted the arsenic concentration in MW-509D and MW-537RS, neither of these wells had high arsenic concentrations in soil or groundwater and are in close proximity to Middle Creek which may cause in increased redox levels due to

surface water inputs resulting in reduced arsenic mobility. Therefore, the arsenic in groundwater concentrations are lower than the predicted values.

- MW-606D showed a higher arsenic in groundwater concentration than the predicted value. This result was consistent with the soil to groundwater calculations completed as part of the December 14, 2021 Evergreen correspondence. The PHREEQE modeling further supported that there appears to be another source for arsenic in groundwater than can be attributed to the source materials around MW-606D. As discussed further below, this source continues to be attributed to upgradient groundwater from SWMU 9.

A sensitivity analysis was done for the PHREEQ modeling for the prediction of the arsenic by varying ORP, pH and DO values to evaluate the parameters that affect arsenic mobilization in groundwater using PHREEQC. Varying pH values at all ten locations showed that arsenic speciations match most closely to those values in the neutral pH range, similar to what is observed within AOI 7. However the modeling was sensitive to low pH, such as what is observed in SWMU 9 groundwater, supporting that pH is important in arsenic mobilization below pH 4. DO values were also varied in the model from 0 to 5 mg/L. As the DO concentrations became more oxidized (closer to 5 mg/L), the predicted arsenic species were less mobile. Consequently, as DO values became more anoxic, the arsenic speciation were similar to the mobile arsenic speciation of As(III). These results suggest that high arsenic in groundwater areas are mobilized in the presence of anoxic conditions. A correlation to lower DO levels were observed in relation to the occurrence of LNAPL in AOI 7 due to enhanced microbial activity in these areas.

Finally, ORP values were varied in the model from -500 mV to +500 mV. As seen with the correlation graphs between arsenic in groundwater and ORP values, in Appendix H, the arsenic speciation resulted in the mobile arsenic speciation of As(III). These results suggest that high arsenic in groundwater areas are mobilized in the presence of reducing conditions.

As discussed above, high concentrations of phosphate aids in the release mechanism of arsenic, as the affinity of phosphate to form surface complexes on iron minerals like goethite and gibbsite phases is higher than that of As(V). The release of arsenic due to competition with phosphate provides an additional source of the generally higher arsenic concentrations in groundwater at greater depths where phosphate is also at high concentrations.

Overall, the fate and transport analysis shows that arsenic mobilization is driven by a combination of processes and that low DO concentrations, negative ORP values, high phosphate in groundwater, and low pH will correlate to arsenic in groundwater. However, even with using advanced modeling techniques, the highest observed arsenic concentrations in groundwater could not be achieved, indicated that even though there are conditions within AOI 7 that increase mobility of arsenic to groundwater that there is not enough arsenic in soils in AOI 7 to result in the observed groundwater concentrations in MW 606 (and presumably MW – 532L) indicating there is an offsite arsenic contribution groundwater to be considered for the IM.

6.3 PCA Analysis

In addition to the PHREEQE modeling, Principal Component Analysis (PCA) analysis was conducted to show the variance between arsenic (dissolved), DO and ORP as well as arsenic (dissolved), pH and ORP of the wells in AOI 7 and SWMU 9 to determine what mechanism is mobilizing arsenic in groundwater. The PCA analysis was completed since the PHREEQE modeling could only be completed on the wells with the additional phosphate and sulfate data, whereas the PCA analysis included all wells sampled in August 2021. The PCA analysis was conducted using the Excel extension XLSTAT by Addinsoft.

The AOI 7 and SWMU 9 wells were divided into 10 groups depending on their locations and flow patterns to assist in identifying relationships between populations in the PCA analysis. These groups were divided as follows and as shown in Figure 28: AOI 7 Shallow Upgradient, AOI 7 Deep Upgradient, AOI 7 Shallow Downgradient, AOI 7 Deep Downgradient, SWMU 9 Shallow Mixed, SWMU 9 Deep Mixed, SWMU 9 Shallow Downgradient, SWMU 9 Deep Downgradient, SWMU 9 Shallow Upgradient, SWMU 9 Deep Upgradient.

Arsenic, pH and ORP were selected as the variables in the first PCA analysis (PCA 1) and arsenic, DO and ORP as the variables in the second PCA analysis (PCA 2). Table 6.3.1 below shows the results of the PCA analysis. The correlation between arsenic, pH and ORP (PCA1) showed a distribution of 93.22% between Factors 1 and 2 and for the correlation between arsenic, DO and ORP, the factors showed a distribution of 76.84%. The eigen values of the first PCA plot (arsenic, pH and ORP) showed a value of 1.865 for Factor 1 and 0.932 for Factor 2. The eigen values of the second PCA (arsenic, DO and ORP), for Factor 1 was 1.360 and 0.945 for Factor 2. The variability of the first PCA was 62.257 for Factor 1 and 31.068 for Factor 2. The variability for the second PCA for Factor 1 was 45.338 and 31.498 for Factor2.

Table 6.3.1 PCA Analysis Results

Eigenvalues:			
PCA 1 with As, pH and ORP			
	F1	F2	F3
Eigenvalue	1.864	0.932	0.203
Variability (%)	62.157	31.068	6.775
PCA 2 with As, DO and ORP			
	F1	F2	F3
Eigenvalue	1.360	0.945	0.695
Variability (%)	45.338	31.498	23.164

The variables plot, Figure 29, of arsenic, pH and ORP between Factors 1 and 2 showed that arsenic was negatively correlated with ORP and has no correlation with pH. The variables plot of arsenic, DO and ORP (Figure 30) showed a positive correlation with DO and negative with ORP. This suggests that arsenic concentrations in groundwater increase with increases in DO concentrations and decreases in ORP. Arsenic in groundwater is not related to changes in pH overall, except for the AOI 7, SWMU 9 Deep Mixed group that are

shown as the yellow triangles in Figure 29 that fall towards the pH and arsenic correlation. This finding is significant because it further supports the hypothesis that there may be a localized pH driven mobilization of groundwater in the deep groundwater between SWMU 9 and AOI 7.

Overall, the PCA analysis is consistent with the soil-to-groundwater calculations and PHREEQC modeling shows that the release process is driven by multiple processes - the presence of low DO concentrations and negative ORP values as well as pH derived from SWMU 9.

7.0 SITE CONCEPTUAL MODEL

7.1 Description and Site Use

The MHIC is located on the north bank of the Delaware River spanning between Delaware and Pennsylvania. The facility frontage extends approximately 4,800 feet along the northern banks of the Delaware River. The MHIC, which is located on industrial property, covers approximately 585 acres of land with access restricted by fencing and security measures. Current operation of the facility (24 hours per day) includes the processing and storage of light hydrocarbon products plus support facilities. To facilitate ship docking, the Delaware River in front of the MHIC (including in front of AOI 7) is routinely dredged.

AOI 7 is located in Delaware and consists of approximately 50 acres of land bounded on the southeast by the Delaware River, the southwest by a property boundary with DVW, and by the Pennsylvania-Delaware state line/AOI 5 on the northeast. Middle Creek runs through AOI 7. The highest and best use for groundwater is recharge to surface water.

7.2 Potential Receptors and DVW PRG for Arsenic in Groundwater

The RFI identified industrial workers and construction workers at the AOI 7 as potential on-Site human health receptors. No groundwater is used or is expected to be used at the MHIC. In relation to potential ecological receptors, the RFI reviewed the U.S. Fish and Wildlife Service (USFWS) National Wetland Inventory which indicated the absence of wetlands within the AOI 7 boundaries. Middle Creek and the Delaware River are classified as riverine systems that are tidal. The Delaware River is classified as an estuarine system that is subtidal with an unconsolidated bottom. At the boundary line between Pennsylvania and Delaware, an area is mapped as an estuarine, intertidal, unconsolidated shore that is regularly flooded (GHD, 2017). During the RFI, the Delaware Department of Natural Resources and Environmental Control (DNREC), Division of Wildlife Species Conservation and Research Program (WSCR) determined that no Significant Habitats are located on or within a 1-mile radius of the AOI 7. In addition, DNREC indicated no records of state-rare or federally listed plants, animals or natural communities and the Site is not within the Delaware National Estuarine Research Reserve. Although, the Delaware River by AOI 7 is slightly saline during low flows, the RFI determined that the benthos and fish are dominated by freshwater species (Tyrawski, 1979) (GHD, 2017).

7.3 Geology and Hydrogeology

Topography in AOI 7 was naturally low lying coastal plain prior to development in the early 20th century. Significant filling occurred in AOI 7 until the 1950s/1960s. Middle Creek was re-routed several times from the late 1800s to the 1950s. Industrial activity at the DVW was ongoing to the west of AOI 7 prior to and during the filling and development of AOI 7. Filling activity at DVW was noticeable adjacent to the AOI 7 boundary as early as 1937, and bermed areas that appear to have received siltation are apparent in the 1950s. A large pond and an apparent disposal pile appear just west of AOI 7 on the DVW property in the 1965 historical photograph. Historical photos show the movement of materials from the adjacent DVW property to locations within the current AOI 7 boundary.

The geology in AOI 7 consists of fill underlain by a silts/silty sand underlain by silty clay, underlain by sands and gravels (Trenton Gravel) underlain by bedrock. A cross-section location map is included as Figure 6 and the AOI 7 geology is shown on Figure 7 (East – West, cross section A-A' along the Delaware River) and Figure 8 (North – South, cross section B-B' along Middle Creek). The fill is thicker towards the Delaware River due to the filling completed to make land as shown in Figure 8. The silts and silty clay shown in Figure 7 represent the top of the Delaware River sediments before AOI 7 was filled, which is underlain by sand and gravel. The shallow wells in AOI 7 are screened in the fill unit and the deep wells in AOI 7 in the area south of the 1953 fill line are screened in the silty clay and overlying silts-silty sands.

The surficial geology in SWMU 9 is dominated by the alum waste that represents a significant portion of the made land in SWMU 9. This alum waste extends to MW-124S and potentially to MW-560 based on the white material noted in the boring logs. Also of note is that the pH in MW-560 is consistently reported to be less than 4. The lateral extent of the alum waste beneath Middle Creek is unknown. The deep wells in SWMU 9 (123D and 124D) shown on Figure 7 are screened in the sand and gravel unit below the silty clay, which is a different geologic unit and lower in elevation than the deep wells in AOI 7.

7.4 Arsenic Distribution in Groundwater

Total arsenic in groundwater concentrations and dissolved arsenic in groundwater concentrations ranged from non-detect to 1,500 mg/L. The highest total and dissolved arsenic concentration was found at deep monitoring well MW-532L, which is consistent with the RFI analytical results. Overall, total arsenic concentrations matched the dissolved arsenic concentrations. The highest dissolved arsenic concentrations in groundwater are located in deep groundwater in the southwestern corner of AOI 7 spanning from MW-606D to MW-534L. Figure 31 shows an isopleth of the arsenic concentrations for concentrations 100 mg/l and above in groundwater detected during the August 2021 sampling as projected on cross section A-A'. As shown on Figure 31, the isopleth depicting the extent of the arsenic plume beneath SWMU 9 is left open due to the fact that MW-123D and MW - 124D were not screened in the same unit or elevation as the deep wells on AOI 7.

The following summarizes arsenic in groundwater by groundwater unit in AOI 7 and SWMU 9.

- As shown in Figure 19, shallow AOI 7 groundwater arsenic concentrations in 2021 range from non-detect to 35 mg/L. The highest dissolved arsenic concentrations in shallow groundwater in AOI 7 are located in the southwestern corner of AOI 7 in the vicinity of MW-606S to MW-607S. This finding is consistent with the findings of the AOI 7 RFI, with the impacted area slightly larger than previously identified due to the installation of additional wells.
- As shown in Figure 19, deep AOI 7 groundwater arsenic concentrations in 2021 range from non-detect to 1,500 mg/L. The highest dissolved arsenic concentrations in deep groundwater in AOI 7 are located in deep groundwater in the southwestern corner of AOI 7 in the vicinity of MW-606D to MW-534L. This finding is consistent with the findings of the AOI 7 RFI, with the impacted area slightly larger than previously identified.
- As shown in Figure 20, historic shallow SWMU 9 groundwater arsenic concentrations range from non-detect to 41.8 mg/L. The highest dissolved arsenic concentrations in groundwater are located in the western portion of SWMU 9.
- Historic deep SWMU 9 groundwater arsenic concentrations (Figure 20) range from non-detect to 0.409 mg/L. It should be noted that the deep wells in SWMU 9, especially those installed along Middle Creek were installed with the objective to screen the sand and gravel (Stratum 4) as identified on the DVW Site. As shown on Figure 7, the deep wells on SWMU 9 are screened at an elevation lower than the deep wells on AOI 7. In addition, the AOI 7 deep wells are screened in the silty clay unit, rather than the sand and gravel. The silty clay unit is more representative of the materials that would have been deposited by materials migrating from SWMU 9 before AOI 7 was filled to make land, so direct comparison of the deep groundwater from MW-123D and MW-124D and the deep wells on AOI 7 is not representative of the same conditions.

7.5 LNAPL Distribution in Groundwater

As shown on Figure 13, LNAPL was observed in 14 monitoring wells in AOI 7 during the 2021 monitoring events with apparent thickness ranging between approximately <0.01 and 8.96 feet during the August 2021 field events. More LNAPL was observed within AOI 7 during the 2021 investigation than was observed during the RFI, which is expected due to aged and weathered nature of the LNAPL which results in very limited LNAPL transmissivity, so it would take a long time for LNAPL to accumulate in monitoring wells.

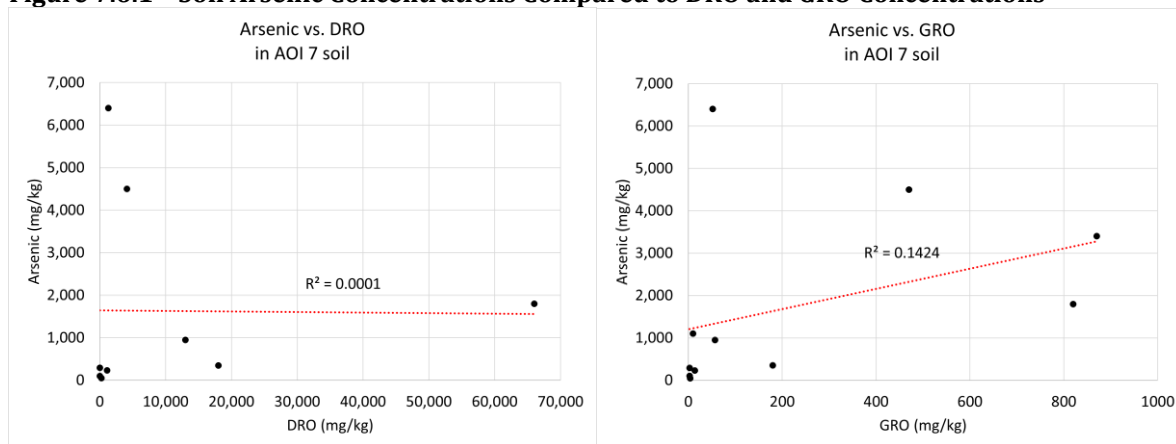
7.6 Potential Source Areas

The EPA had identified three potential sources of arsenic in AOI 7 to be further investigated; petroleum hydrocarbons (as DRO/GRO and LNAPL), pyritic ore waste and other soils in AOI 7 not sampled during the RFI. Evergreen had previously identified arsenic in AOI 7 soils in the southwestern corner of AOI 7 and arsenic in SWMU 9 soils as potential sources for the observed arsenic in groundwater. Each of these is discussed below in relation to the findings of the 2021 investigation activities.

Petroleum Hydrocarbons

DRO and GRO samples were collected from each monitoring well boring, as requested by the EPA, and these values were compared to arsenic concentrations in soil as shown in Figure 7.6.1 below.

Figure 7.6.1 – Soil Arsenic Concentrations Compared to DRO and GRO Concentrations



Arsenic soil concentrations had no meaningful correlation to either DRO or GRO concentrations in soil. Based on the lines of evidence above, DRO and GRO are not a source of arsenic in the subsurface at AOI 7.

LNAPL

LNAPL is present in AOI 7, as shown in Figure 13. The 2021 field activities included sampling of LNAPL at three locations with varying arsenic concentrations found in groundwater. These results are provided in Table 12. MW-182 (that has the lowest arsenic in groundwater concentration as non-detect) had an arsenic in LNAPL concentration of 63 mg/L compared to MW-607D that had an arsenic in groundwater concentration of 100 mg/L and a LNAPL in arsenic concentration of 8.9 mg/L (lower than MW-182). Also note that MW-532L has the highest arsenic in groundwater concentration and does not have any LNAPL present in the well. Comparing the level of arsenic detected in the LNAPL to soil concentrations and the lack of correlation between the arsenic concentrations in LNAPL and groundwater, LNAPL is not a source of arsenic to groundwater in AOI 7.

Pyritic Ore Waste

Pyritic ore wastes are known to have high arsenic concentrations. Pyritic ore was noted historically as waste in SWMU 9 that was generated during the production of sulfuric acid and is a known source of arsenic at the General Chemical site. However, according to the soil boring logs provided in the 1989 Ethylene Complex History of Landfilling Report, seven soil borings in AOI 7 noted "pyritic waste" within the soil column. These soil borings include soil borings 9, 13, 14, 16, 20, 22, and 24, which were completed in 1958, as identified in Evergreen's April 13, 2021 correspondence. Prior to the July 2021 field activities the three closest locations (MW-537, MW-536 and MW-562) to the 1958 borings did not note any pyritic waste. In addition, these locations did not have elevated arsenic

detections in soils in the 0-10 foot depth interval where the pyritic waste was mostly noted, as summarized below from RFI data:

- MW-537 – 41 ppm, collected at a depth of 9 to 10 feet,
- MW-536 – 136 ppm, collected at a depth of 1.5 to 3.5 feet, and
- MW-562 – 60 ppm, collected at a depth of 8 to 9 feet.

In addition, historic groundwater data from MW-537, MW-536 and MW-562 did not have elevated arsenic concentrations compared to other monitoring wells on site.

Soil borings AOI7-BH-21-001 through AOI7-BH-21-006 were completed in July 2021 at the locations where pyritic waste was identified in the 1958 boring logs. (Note: the planned boring to investigate historic boring 24 could not be completed due to safety concerns. This was not identified as a data gap since the arsenic groundwater concentrations in this portion of the AOI 7 are very low and the remainder of the borings were able to be completed). No pyritic ore was visually observed during characterization of all six borings. Soil boring logs are provided in Appendix D. The highest arsenic concentrations in these six locations in the locations where pyritic ore were noted in the 1958 logs are summarized below:

- AOI7-BH-21-001 – 20 mg/kg, collected at a depth of 6 to 10 feet,
- AOI7-BH-21-002 – 6.9 mg/kg, collected at a depth of 10 to 15 feet,
- AOI7-BH-21-003 – 100 mg/kg, collected at a depth of 10 to 15 feet,
- AOI7-BH-21-004 – 18 mg/kg, collected at a depth of 10 to 15 feet,
- AOI7-BH-21-005 – 12 mg/kg, collected at a depth of 0 to 6 feet, and
- AOI7-BH-21-006 – 950 mg/kg, collected at a depth of 15 to 20 feet.

In addition, low dissolved arsenic concentrations in groundwater are present in the vicinity of these borings, as shown in Figure 14. Due to the lack of observation of pyritic ore in any of the soil borings completed in July 2021, the low arsenic concentrations in soil and the low arsenic concentrations in groundwater, pyritic ore is not considered a source of arsenic at AOI 7.

Arsenic in AOI 7 Soils

As shown in Figures 14 and 15, the highest arsenic concentrations in soil in AOI 7 are located in the southwestern area of AOI 7, followed by concentrations along the southern shoreline of AOI 7 (south of the historic shoreline). Arsenic concentrations ranged from non-detect to 11,000 mg/kg in AOI 7. The highest arsenic detections in soil in AOI 7 correlate with observed high arsenic concentrations in groundwater. However, as discussed in Section 6.0 the modeling still cannot produce the high groundwater concentrations observed in the southwestern corner of AOI 7 based solely on the AOI 7 arsenic soil concentrations and observed geochemical conditions in that area. These findings support that while there is likely some input from arsenic in soils in the southwestern portion of AOI 7 (which were historically deposited from SWMU 9), there may be an additional source to groundwater, as is discussed below.

Arsenic in SWMU 9 Soils

The highest arsenic in soil concentration in AOI 7 and SWMU 9 was found to be located in SWMU 9 at MW-124S with a concentration of 14,100 mg/kg at 14 to 16 ft bgs, as shown on Figure 15. One of the apparent discrepancies is the fact high arsenic concentrations in groundwater are not found associated with these high arsenic soil concentrations. As shown on Figure 7, the deep wells located along the eastern boundary of AOI 7 (MW-123D and MW-124D) are screened in the sand and gravel unit, not the silty clay unit, as are the deep wells in AOI 7. The SWMU 9 deep wells are also screened at a deeper elevation than the AOI 7 deep wells, so they may not be screened at the proper depth to detect high arsenic concentrations in groundwater. Another consideration is the fact that SWMU 9 was a settling basin for alum waste, and alum was designed to hold arsenic and other waste from mobilizing. The arsenic may be mobilized only on the boundaries of the alum waste when the geochemical conditions allow for arsenic mobilization, similar to what is observed on the western side of SWMU 9, as shown on Figure 20. Based on the soil data in SWMU 9, arsenic in SWMU 9 soils remains a potential source for a portion of the observed arsenic groundwater plume in AOI 7. The potential mechanisms for arsenic mobilization are discussed in Section 6.0 and Section 7.7.

7.7 Fate and Transport

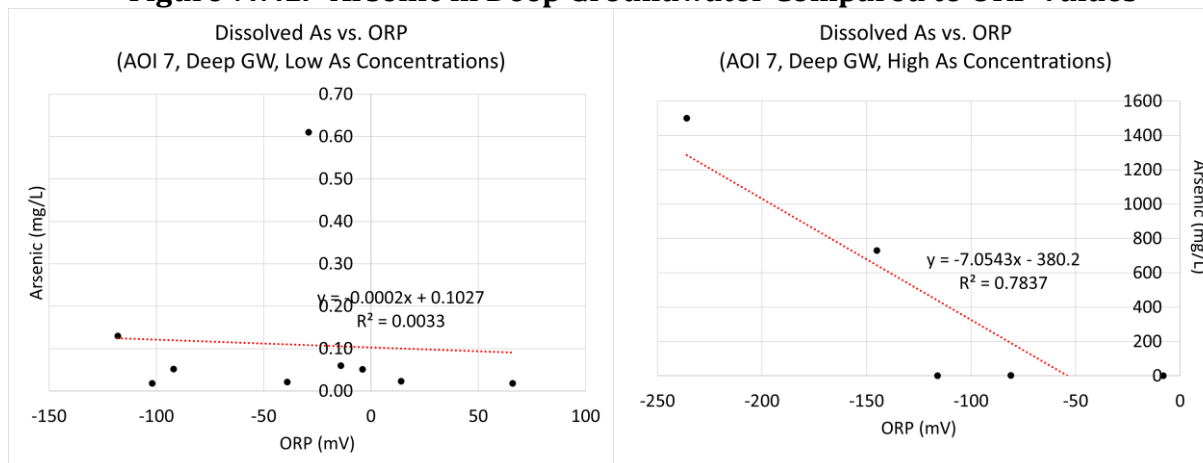
As discussed in Section 6.0, there are three primary factors that affect the fate and transport of arsenic in groundwater: the redox environment, pH, and adsorption/precipitation of arsenic onto aquifer solids, particularly iron oxyhydroxides. These factors are governed by the geochemistry, hydrogeology and the mineralogy of the groundwater matrix. Under oxidizing conditions (high Eh), and aerobic conditions arsenates (As^{+5} ; arsenate, immobile) are more stable. A zone with depleted oxygen (anoxic conditions) and lower Eh values occurs below the aerobic zone will have a mixed arsenic speciation that is dependent on pH. At acidic pH values ($\text{pH} < 4$), trivalent (As^{+3} ; arsenite) species are dominant in the transition zone; at higher pH values ($\text{pH} > 4$) pentavalent arsenic becomes present in increasing proportions as pH values increase (until pH above 8 is reached). Localized redox conditions in the transition zone can be lowered by the presence of soil organics which can cause reducing conditions, resulting in more arsenite (As^{+3}). In a reduced zone, the redox conditions will shift the arsenic speciation toward the arsenite ion. Since arsenic species are more soluble than arsenates at most Eh-pH ranges, arsenic mobility and hence total arsenic concentrations in groundwater will increase under reducing conditions (Brown et. al, 2021)

In the presence of LNAPL, anaerobic biodegradation (typically via sulfate-reducing bacteria or methanogenesis) can occur and generate these reducing conditions in the area of the LNAPL. Under these conditions, arsenic in the form of arsenate can be reduced to the more mobile form, arsenite (Ford, 2007). ORP and DO groundwater conditions across AOI 7 are presented in Figures 23 and 25. LNAPL was presented in 9 shallow wells and 4 deep wells across AOI 7 during the August 2021 groundwater round (Figure 13). Among the wells that showed LNAPL presence at the southwestern corner of AOI 7, redox values are slightly reducing to strongly reducing and range from -4 to -236 millivolts (mV). The area of most reducing conditions is located in the southwestern corner of AOI 7, where the highest

arsenic in groundwater concentrations are located. DO concentrations in the southwestern area of AOI 7 reflect the anaerobic conditions with DO concentrations less than 0.5 mg/L. Areas in AOI 7 to the center and to the north show mostly positive to slightly reducing conditions where LNAPL is not present and there are lower arsenic in groundwater concentrations.

ORP values were also correlated to arsenic concentrations in groundwater. Figure 7.7.1 shows the correlations of arsenic in deep groundwater to ORP values.

Figure 7.7.1. Arsenic in Deep Groundwater Compared to ORP Values



The plot on the left represents data from wells that showed low dissolved arsenic in groundwater and the plot on the right represents data from wells that showed high dissolved arsenic in groundwater. There is no correlation to ORP in areas of low dissolved arsenic in groundwater. For the southwestern area of AOI 7, there was a strong correlation with high arsenic concentrations in groundwater and negative ORP values. This correlation in deep groundwater supports the theory of redox conditions contributing to the mobility of arsenic in deep groundwater. Note that arsenic in shallow groundwater did not show a strong correlation to ORP values.

Arsenic mobility in redox zones can be mitigated by the presence of mineral precipitates on the soil grains, particularly iron oxyhydroxides. Both arsenate and arsenite can be adsorbed by these materials, thus reducing their mobility. However, the adsorption of arsenic and its solubility through this mechanism is a function of pH, as discussed in Section 6.0 At low pH (pH < 4), the solubility of arsenic species increases due to dissolution of the underlying sorption sites that are present as ferric oxyhydroxide mineral coatings on aquifer solids. The low pH shows iron typically present as ferrous iron that is soluble. This change eliminates the sorption sites and releases the adsorbed arsenic to groundwater (Brown et al, 2010). A high pH (pH > 9) also releases arsenic through co-precipitation processes. This process is thought to be occurring within the southwestern and southern portion of AOI 7 driven by low pH from SWMU 9 (MW-560) as evidence by the positive correlations between dissolved iron and arsenic in groundwater and the negative correlation between iron in soil and arsenic in groundwater in this area (Appendix H).

The pH conditions in groundwater for AOI 7 and SWMU 9 are shown in Figure 24. Four shallow wells displayed pH values less than 4: MW-14 and MW-19 on SWMU 9 and MW-48 and MW-560 on AOI 7. No pH values exceeded 7.5. The four wells with a pH less than 4 are located on the western side of Middle Creek. Appendix H contains the graphs comparing arsenic in groundwater to pH values at individual wells. The only subgroup that showed a correlation to pH was deep groundwater in wells that showed high arsenic concentrations (i.e., located in the southwestern corner of AOI 7). There are a few considerations for impacts of pH on arsenic mobility in AOI 7 and SWMU 9. In the area of the mixed groundwater zone, Figure 28, there is a downward gradient from shallow to deep, which would allow the shallow wells (i.e. MW-560) with low pH to mobilize arsenic which could migrate downward and then laterally towards AOI 7 (MW- 606 and MW- 532L).

Based on the geochemistry investigated at the site along with the presence of LNAPL, the mobility of arsenic in groundwater is influenced by the areas with low redox conditions, which are likely enhanced by the biodegradation of LNAPL at the site. A zone with depleted oxygen (anoxic conditions) and lower Eh values will have a mixed arsenic speciation that is dependent on pH, which is what the fate and transport modeling in Section 6.0 predicts at the Site. In other words, the potential mobility for arsenic in the southwestern portion of AOI 7 is based on localized arsenic soil concentrations, low ORP and low DO likely driven by the presence of LNAPL causing enhanced biodegradation. However, the modeling, as supported by site observations, cannot predict the very high concentrations observed in MW-606 and MW-532L, indicating that there may be a second process driven by pH and groundwater flowing from SWMU 9 to AOI 7 that is adding a large component of the observed arsenic concentrations in groundwater in the southwestern portion of AOI 7. These findings are significant in order to properly design the IM requested by the EPA for AOI 7 groundwater.

7.8 Pathway Evaluation

The pathway of concern identified by the EPA is groundwater to porewater, with the stated goal of the IM to achieve the groundwater arsenic PRG (calculated for the DVW site). This PRG was developed to protect the benthos in porewater in Honeywell's proposed sediment cap in the Delaware River (the cap was proposed to address DDx in river sediments). Therefore, Evergreen completed a pathway analysis to further assess potential impacts to porewater from groundwater discharge in AOI 7.

Mass flux was calculated based on three zones, as shown on figures in Appendix I. These zones were selected based on the groundwater gradient and arsenic concentrations in groundwater above the groundwater arsenic PRG (calculated for the DVW site) in each area, as shown in the figures in Appendix I. The results of this mass flux are summarized below (note that none of the wells in Zone C had arsenic concentrations above the DVW PRG.)

	Predicted Mass Flux (g/d)
Zone A	0.111
Zone B	0.0354
Zone C	0.0

These mass flux calculations were very conservative based on the fact that during porewater sampling in front of SWMU 9 and AOI 7, several porewater sampling locations had so little sample volume due to low flow or siltation in the sample that no or reduced sample analyses were completed. This lack of flow in the porewater further supports the lack of significant mass flux from groundwater to porewater. Further, the DVW Supplemental Pathway Evaluation (AMEC Foster Wheeler, 2017) identified that 99% or more of the arsenic being bound to sediment solid phases, including iron and arsenic sulfides sorption. The strong sequestration of arsenic in sulfide phases within sediments indicates sediment is a net sink of arsenic at the site and is expected to continue to act as such as long as sulfate is available to sustain microbial sulfate reduction. These analyses call into question the mass loading and arsenic availability to receptors based on the completed activities.

7.9 Risk Characterization

The results of the HHRA in the AOI 7 RFI indicated that there are no unacceptable reasonable maximum exposure (RME) cancer risk or non-cancer HI estimates for human exposure at or around AOI 7 under current or potential future land uses. Arsenic was evaluated as a groundwater flux to assess attainment of the groundwater CAO in the RFI. Based on this evaluation, the arsenic concentrations in groundwater in the discharge zone to the Delaware River were identified in attainment of DRBC criteria and the CAO in the RFI. A SLERA was completed during the AOI 7 RFI. The SLERA identified no unacceptable risks to ecological receptors in sediment and surface water. Only samples from the most downstream stations in Middle Creek had concentrations of DDx or arsenic exceeding the values developed by Environ on behalf of Honeywell for its sediment corrective actions in Middle Creek. Since these impacts were not attributed to former Sunoco operations and a cap was proposed to address sediments in Delaware River by Honeywell, the risk to Middle Creek from these detections was acceptable and no further action in Middle Creek was identified in the RFI to be carried into the CMS.

The EPA has identified the protection of benthos in porewater in Honeywell's proposed sediment cap in the Delaware River as the driver for the development of the arsenic groundwater PRG. There are several assumptions in the development of the PRG that were further evaluated as part of this IM Workplan in order to assess how they may influence the design of an IM for AOI 7. The assumptions in the derivation of the arsenic groundwater PRG for the DVW Site include the underlying saltwater chronic national recommended water quality criterion (NRWQC) of 36 ug/l and additional aquatic toxicity data identified from the USEPA's online ECOTOX database (USEPA 2017). The arsenic groundwater PRG (1,253 ug/l) was developed to protect the most sensitive benthos receptor (data for the polychaete worm, *Capitella capitella*) based on a chronic exposure in a saltwater

environment. Based on the data utilized in the SLERA for the RFI, the Delaware River by AOI 7 is only slightly saline during low flows, and the benthos and fish are dominated by freshwater species. Therefore fresh water species and the DRBC's arsenic value for surface water (150 mg/l) were used as the basis of the SLERA in the RFI. In addition, the area of potential impacted habitat is very limited due to the area of the proposed cap by Honeywell to be only in front of the southwestern corner of AOI 7, as shown in the Supplement Study Area Investigation Report, Environ, 2017, and due to the fact that the Delaware River is dredged beyond the piers, as shown in Appendix A. It is beyond the scope of this IM Workplan to develop an alternative arsenic PRG for groundwater in AOI 7, but based on these considerations development of a PRG through an ecological risk assessment, similar to the process followed in the AOI 7 RFI is recommended to be discussed to be able to establish the appropriate remedial endpoint for an IM for arsenic in groundwater at AOI 7.

8.0 CONCLUSIONS AND RECOMMENDATIONS FROM THE 2021 INVESTIGATION ACTIVITIES

The following conclusions and recommendations are provided based on the results of the 2021 investigations in AOI 7 combined with the historical data collected in both AOI 7 and SWMU 9 in order to inform the path forward for the IM in AOI 7. The conclusions are organized in relation to the objectives of the IM workplan introduced in Section 1.1, which are 1) what is the source material for the observed arsenic concentrations, 2) what conditions exist that are resulting in the mobilization of the arsenic; and 3) what is the appropriate remedial action objective for the IM?

What is the source area for the observed arsenic concentrations?

- Before AOI 7 was filled and made land, waste materials from SWMU 9 were seen in historical photos migrating into the southwestern portion of AOI 7.
- Geology in AOI 7 consists of fill (which is thicker in the areas of made land along the Delaware River), underlain by silts/silty sands and silty clays which represent the top of the Delaware River sediments prior to the land being filled, underlain by sand and gravel of the Trenton formation. The deep wells in AOI 7 are screened in the silts/silty sand and silty clays. The deep wells in SWMU 9 are screened in the sand and gravel unit. Deep wells in SWMU 9 may not be detecting that there is a source area in SWMU 9 contributing to arsenic in AOI 7 groundwater.
- Groundwater flow in both the shallow and deep groundwater is towards Middle Creek and the Delaware River, and is influenced by current and former locations of Middle Creek. Different zones were identified in the shallow and deep groundwater units in AOI 7 and SWMU 9. Most of these zones were distinct but a potential mixing zone, especially in deep groundwater, was identified along the southern portion of AOI 7 and SWMU 9 in the vicinity of Middle Creek.
- Petroleum hydrocarbons (DRO/GRO and LNAPL) are not a source to arsenic in groundwater in AOI 7.
- Pyritic ore waste is not present in AOI 7 and is not a source to arsenic in groundwater in AOI 7.

- No additional soils beyond the southwestern corner of AOI 7 were identified as potential source of arsenic to groundwater in AOI 7 and AOI 7 is well characterized and delineated for arsenic in soil.
- Arsenic in soils and potentially groundwater in SWMU 9 remains a potential contributor to the observed arsenic concentrations in the southwestern corner of AOI 7 based on the completed fate and transport modeling and the screened depth of the deep wells in SWMU 9.

What conditions exist that are resulting in the mobilization of the arsenic?

- Reduced conditions in the southwestern portion of AOI 7, potentially due to the presence of LNAPL, combined with arsenic in soil and other geochemical conditions can help mobilize arsenic to groundwater. However, as stated above, all of the observed arsenic in the groundwater in the southwestern portion of AOI 7 cannot be attributed solely to the conditions in AOI 7. The low pH conditions in the western edge of SWMU 9 are also identified as a condition that can result in the mobilization of arsenic in groundwater.
- Very little arsenic groundwater flux into the Delaware River was identified from AOI 7, which is further supported by the difficulty collecting enough volume of porewater samples in front of both AOI 7 and SWMU 9. Also, work completed in SWMU 9 supports 99% or more of the arsenic is bound to sediment solid phases and that arsenic will be immobilized when it discharges to aerobic conditions in surface water. These factors all support that the groundwater to porewater pathway may not be significant in AOI 7.

What is the appropriate remedial action objective for the IM?

- The AOI 7 RFI found that arsenic in groundwater discharging the Delaware River met the CAOs established for AOI 7 and would attain the DRBC criteria. The RFI did not identify any unacceptable human health risks for arsenic and the SLERA found that potential ecological risks would be addressed by the planned sediment cap in front of AOI 7 by Honeywell.
- The arsenic in groundwater PRG developed for the DVM Site may not be appropriate for AOI 7 due to fact that it is based on a salt water endpoint, low flux from groundwater to porewater and limited exposure area for the benthos driving the PRG.

The recommended path forward to complete the IM design for AOI 7 is to:

- Collect high resolution groundwater flow information for groundwater migrating between AOI 7 and SWMU 9 to determine the appropriate remedy between the two areas.
- Collect sediment and porewater samples for arsenic in the Delaware River in front of AOI 7.
- Discuss Honeywell's proposed cap design with Honeywell and the EPA to determine the path forward for pilot tests for the IM , development of an alternative PRG for

arsenic in groundwater for AOI 7 and/or completion of a SLERA for arsenic in groundwater.

9.0 INTERIM MEASURE

The EPA requested that the IM Workplan include the proposed IM to address arsenic in groundwater above the arsenic groundwater PRG developed for DVW. As presented in Section 8.0, selection of an IM at this time would be inappropriate since before the IM can be selected and designed, the appropriate remedial endpoint needs to be established as discussed in Section 8.0 and if needed, pilot testing conducted to confirm applicability of various remedies. In addition, significant site constraints exist within AOI 7 that need to be considered in relation to a potential IM (active rail line located adjacent to Middle Creek and the Delaware River) which will require further discussion with facility owners/operators including MHIC and Conrail personnel. In addition, the presence of underground obstructions, such as the wooden retaining wall encountered during the installation of MW-559, needs to be considered and incorporated into an IM approach. However, to be responsive to the EPA's request, Evergreen has prepared a summary of the potential remedial options that could be considered for AOI 7 and have included those in Appendix J. The list of potential remedial options that could be considered is also shown below.

- In-situ treatment options
 - Sulfide/zero-valent iron slurry injections
 - pH adjustment injections
 - Permeable reactive barrier
 - Solidification/stabilization
 - Barrier wall
 - Sediment cap
 - In-situ soil flushing
- Ex-situ treatment options
 - Capping
 - Excavation
- Ex-situ groundwater treatment options
 - Precipitation/co-precipitation
 - Ion exchange

Below is a potential approach for completing a two stage pilot test to address arsenic in groundwater in AOI 7. In addition, Evergreen will consider what elements could be added to Honeywell's proposed cap in front of AOI 7 to enable it to also treat arsenic in porewater, which may potentially be extended further along AOI 7. To date, Evergreen has not discussed this with Honeywell, nor seen any of the plans for this cap, except for a general implementation area, so Evergreen cannot provide more details on this approach in this IM Workplan.

Pilot Test Approach

Because of the complex groundwater geochemistry, a pilot test is first recommended to determine the remedial design's viability to treat arsenic in groundwater. The pilot test may involve a step-wise process that could include: (1) sulfide/zero-valent iron slurry injections to immobilize AOI 7 arsenic in groundwater in the southwestern portion of AOI 7 near MW-606 and MW-531D, and/or (2) pH adjustment to immobilize arsenic coming from SWMU 9 in the vicinity of MW-560. Prior to completing the pilot test, batch scale column tests could be completed with site soils and groundwater to optimize dosing and design of the pilot test.

Based on the outcome of the column tests, the slurry injections may use a sulfide/zero-valent iron product that will precipitate arsenic through the production of iron arsenic sulfide minerals that become insoluble in groundwater. This slurry could be prepared on site using a tank and a mixer/pump to create a low viscosity, aqueous slurry. The mixed slurry could then be injected into open rods placed in the ground via direct push methods. As the slurry is injected, the rods elevate out of the ground to allow dispersion of the slurry to create conditions for precipitation/adsorption of arsenic. Arsenic in groundwater could be monitored in nearby wells (i.e., MW-532L, MW-531L, MW-606D) to determine removal efficiencies. The approximate location of this phase of the pilot test is shown in Appendix J.

The groundwater could be monitored and if additional arsenic loading is occurring from flow from SWMU 9 that would result in accelerated depletion of the sulfide/iron slurry, a pH adjustment system pilot system could also be implemented along Middle Creek towards the southwest corner of AOI 7 to intercept low pH groundwater coming from SWMU 9 that has mobilized arsenic in groundwater at AOI 7. Similar to the column tests proposed to be completed prior to the sulfide/iron slurry pilot test, column tests could be completed to identify the proper additives for the pH adjustment using Site soils and groundwater. Then titration tests could be conducted on groundwater prior to injections to determine the buffer capacity of the groundwater to inform the proper dosing. The pH adjustment may use caustic soda (or other additive) at a dose that will bring the pH to approximately 6.5 to 7.5 that will not mobilize arsenic further on AOI 7. Caustic soda could be introduced into the subsurface via direct push methods, as planned for the slurry injections. The injections will occur in a line parallel to Middle Creek. The general area is shown in Appendix J.

10.0 PROPOSED INVESTIGATION ACTIVITIES

In accordance with the conclusions and recommendations in Section 8, the following activities are proposed for AOI 7.

10.1 Groundwater Flow Measurements

Groundwater is influenced by tidal variations from the Delaware River in monitoring wells located along Middle Creek and along the shoreline of the Delaware River. Because AOI 7 and SWMU 9 wells are widespread, it is difficult to gauge all groundwater wells across both sites while the tide is stable. In addition, there appears to be flow in deep groundwater from SWMU 9 to AOI 7. Therefore, one of the recommendations for additional data collection to inform the IM is to collect high-resolution groundwater flow measurement by

installing groundwater flow meters in five shallow wells and 5 deep wells focusing in the southwestern portion of AOI 7 and the southeastern portion of SWMU 9. Options for flow meters include:

- Colloidal borescopes - measure groundwater velocity and horizontal flow direction in real-time using a down-well sensor set to depth-specific intervals. These borescopes record thousands of data points per minute by tracking colloids present in the groundwater,
- Submersible Water Level Loggers – using a pressure transducer, these measure groundwater levels, saltwater intrusion, and discharge monitoring, and
- Digital Water Velocity Meter - (or positive-displacement flow meters) accumulate a fixed volume of fluid and then count the number of times the volume is filled to measure flow.

Colloidal borescopes are the most applicable to the objectives of measuring groundwater levels and flow direction in wells located at AOI 7. Data would be logged electronically and processed in real-time per minute and matched with tidal schedule data from the Delaware River. Correlations with staff gauge in Middle Creek and Delaware River would also be made to the data collected by the colloidal borescopes.

10.2 Sediment Sampling

Sediment sampling is proposed based on the USEPA's recommendation in the June 23, 2021 letter "Request for Interim Measures Workplan for AOI7". The additional work requested included sampling sediment in front of AOI 7 and delineating the areal extent of arsenic in sediment to the arsenic sediment PRG of 170 mg/kg.

Sediment core samples are proposed for collection at eight locations off the AOI 7 shoreline as shown in Figure 32. Note that five sediment sample locations are paired with proposed porewater locations. Chemical analyses of the eight sediment samples include sulfide, total organic carbon (TOC) total solids (TS) analysis, and total arsenic analysis. One field duplicate will be collected and submitted for sulfide, TOC, TS, and total arsenic analysis as well.

Each sediment sample will also be analyzed via selective sequential extraction (SSE) to quantify the amount and proportion of arsenic in solid phase associations. The SSE process consists of five extraction steps to define arsenic fractions that include: an F1 soluble fraction (water-soluble arsenic), F2 exchangeable fraction (weakly adsorbed arsenic), F3 reducible fraction (arsenic associated with iron oxides and oxyhydroxides), F4 oxidizable fraction (arsenic associated with sulfides and/or organic matter) and F5 residual fraction (tightly bound arsenic). These analyses will help to determine how arsenic in sediment (as well as dissolved arsenic in porewater) is partitioning and mobilizing. The SSE method in sediment uses porewater samples collected anoxically by centrifugation of sediment collected for the SSE. After processing the SSE, centrifuge tubes will be filled with remaining homogenized sediment in a sealed glove box under nitrogen and will be centrifuged for a minimum of 30 minutes. Porewater will be decanted from the centrifuge tubes, filtered, and preserved for arsenic speciation analysis under nitrogen.

In order to obtain preserved samples for sulfide analysis, a sample will be extracted from an aliquot from the preserved push cores. The push core samples will be capped with overlying surface water in order to keep the sediment anoxic and will be shipped on ice in sealed Mylar bags with oxygen-absorbent packets. The cores will be processed in a sealed glove box under nitrogen and the overlying surface water will be removed from each core within the glove box by decanting from the top of the core using a pipet and discarding the water. Each individual core was homogenized and an aliquot of sediment will be removed for SSE of arsenic. The standard operating procedure (SOP) for the sediment sampling at AOI 7 is provided in Appendix K.

10.3 Porewater Sampling

Porewater sampling is also proposed based on the USEPA's recommendation in the June 23, 2021 letter "Request for Interim Measures Workplan for AOI7". The additional work requested included sampling porewater in front of AOI 7 and delineating the areal extent of arsenic in porewater that exceeds 1,253 ug/L.

Porewater samples are proposed for collection at 13 locations off the AOI 7 shoreline as shown in Figure 32. Field collected porewater samples will be analyzed for major ions (anions and metals), alkalinity, sulfide, dissolved arsenic and arsenic speciation analysis as shown in Table 13. One field duplicate will be collected.

As noted in the 2017 *Supplemental Pathway Investigation Results Report*, and the work completed by the USCOE in front of AOI 7, it is anticipated that shallow interval porewater may not be recovered in volumes sufficient for analysis. Previous data collection of porewater using the micro push-point method in front of DVW and AOI 7 was complicated by the fine-grained, compacted nature of the nearshore surficial sediments that limited recoverable porewater volume and led to clogging of the sampling devices. Instead of micro push-point samplers, porewater samples will be collected using passive porewater samplers called peepers. Peepers quantify the dissolved form of constituents to provide more accurate data regarding contaminant bioavailability to environmental receptors. The peepers consist of chambers overfilled with deionized oxygen-free water (DI) that is held within the chambers by a porous membrane and the overlays. The peepers will be degassed prior to deployment. Peepers will be deployed by inserting into the sediment to a depth of 6 inches below the mudline or as deep as possible to allow the surrounding interstitial water to infiltrate the sampler. The peeper will be deployed for a minimum of 28 days prior to retrieval. This will allow for better sample collection and to also simulate chronic conditions (which the current arsenic in groundwater PRG is based upon).

For porewater retrieval, the sample would be removed from the chamber using a glass syringe. While collecting porewater to fill laboratory-provided containers, the porewater pH, temperature, and conductivity should be measured from additional sample volume. Following porewater collection into the laboratory-supplied containers, the porewater samples needs to be placed in a cooler at 4 degrees Celsius for transport to the field facility where they will be packaged for shipment. The SOP for the porewater sampling at AOI 7 is provided in Appendix K.

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